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Spaceborne Ocean Intelligence Network

SOIN - fiscal year 10/11 year-end summary

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This document is the SOIN project FY 2010/2011 annual report to the Canadian Space Agency's Government Related Initiatives Program.

Abstract

The Spaceborne Ocean Intelligence Network (SOIN) is a six-year research and operational development project that addresses barriers to developing and implementing oceanographic applications derived from Earth-observation sensors such as RADARSAT-2 and MODIS, capabilities that will be provided by the Polar Epsilon Project, combined with existing AVHRR and MERIS sensor data. The project is divided into two phases. The recently terminated three-year Phase I focused on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and an ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT-2 synthetic aperture radar (SAR) imagery. The ongoing three-year Phase II will focus on operationalization and implementation of SOIN capabilities. The SOIN project began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. This report provides a summary of project activities and accomplishments in FY 10/11.

Résumé

Le réseau spatial de renseignements océanographiques (RSRO) est un projet de recherche et développement opérationnel d'une durée de six ans qui porte sur l'étude des obstacles à l'élaboration et à la mise en œuvre d'applications océanographiques dérivées des capteurs d'observation de la Terre, comme RADARSAT-2 et MODIS, capacités qui seront fournies dans le cadre du projet Polar Epsilon et combinées aux données des capteurs AVHRR et MERIS. Le projet se divise en deux phases. La phase 1, qui s'est étalée sur trois ans et qui vient de se terminer, a porté sur le développement de produits de pointe appelés à fournir des données sur la visibilité des plongeurs et la température de la surface de la mer, des outils opérationnels, une infrastructure de soutien et une capacité de détection des fronts thermiques, des tourbillons et des limites des masses d'eau au moyen de l'imagerie de radar à synthèse d'ouverture (RSO) de RADARSAT-2. La phase II en cours, d'une durée de trois ans, portera sur l'opérationnalisation et la mise en œuvre des capacités du RSRO. Le projet a débuté en juin 2007 grâce à un financement de l'Agence spatiale canadienne (ASC) par l'entremise de son Programme d'Initiatives gouvernementales en observation de la Terre (IGOT). Le présent rapport donne un résumé des activités et des réalisations du projet durant l'exercice 2010-2011.

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Executive summary

Spaceborne Ocean Intelligence Network: SOIN - fiscal year 10/11 year-end summary

Darryl Williams; Brenda DeTracey; Paris W. Vachon; John Wolfe; Will Perrie; Pierre Larouche; Chris Jones; Joe Buckley; Sean Pecknold; Cristina Tollefson; Richard E. Thomson; Gary Borstad; Wayne Renaud; DRDC Ottawa ECR 2011-145; Defence R&D Canada – Ottawa; October 2011.

Introduction: The SOIN project began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. Led by MetOc Halifax, SOIN is a six-year research and operational development project that addresses barriers to developing and implementing operational oceanographic applications derived from Earth-observation sensors. The project is positioning east and west coast MetOc centres to take full advantage of the Near Real Time Ship Detection (NRTSD) and Environmental Sensing (ES) capabilities being implemented for the Canadian Forces (CF) by the Polar Epsilon Project.

SOIN is divided into two phases. Phase I was completed in March 2010 and focused on developing state-of-the-art sea-surface temperature (SST) and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT-2 synthetic aperture radar (SAR) imagery. The ongoing three-year Phase II began in April 2010 and focuses on implementation and operationalization of SOIN outputs. Three new WP's commenced in FY 10/11, and with these came three new partners – the Institute of Ocean Sciences (IOS) in Victoria BC, the Royal Military College (RMC) of Canada in Kingston ON, and Defence Research and Development Canada – Atlantic (DRDC Atlantic) in Halifax NS. This report provides a summary of project activities and accomplishments for FY 10/11, and the work plan for FY 11/12.

Results: In addition to WP 1 (Project management, delivery, and communication), SOIN had eight active work packages in FY 10/11:

- WP 2 – Automated Processing System. MetOc Halifax is operating a Canadian version of the US Navy's Automated Processing System (C-APS), and is processing MODIS, AVHRR, and MERIS data. RADARSAT-2 data ordering and de-confliction procedures (with the Canadian Ice Service (CIS), Defence R&D Canada (DRDC) and the Royal Military College of Canada (RMC)) are well established, MetOc Halifax's Ocean Work Station (OWS) was upgraded to ingest shape files of RADARSAT-2-derived thermal features. Furthermore, the Department of Fisheries and Oceans' (DFO) Institute Maurice Lamontagne (IML) completed preparation work for the frontal climatology to be developed and implemented in the upcoming year.

- WP 3 – SAR processor, Image Analyst Pro (IA Pro) and Commercial Satellite Imagery Acquisition Planning System (CSIAPS). DRDC Ottawa successfully installed and continued to upgrade the IA Pro and CSIAPS software tools, two cutting-edge software packages instrumental to the acquisition, archiving and evaluation of space-based imagery. DRDC Ottawa also upgraded within IA Pro the SAR Ocean Feature Detection Tool

(SOFDT), which generates numerous SAR-derived products including shape files of RADARSAT-2-derived features and new SAR-derived output products. A capability for interactive vector feature validation was also implemented to assist with the gathering of feature attributes for statistical analysis.

- WP 4 – Ocean features from SAR. DFO's Bedford Institute of Oceanography (BIO) continues to investigate the physical characteristics of the marine atmospheric boundary layer (MABL) to determine methodologies for their identification, and their research has yielded some interesting and important results. Of particular note, they have demonstrated that the fine-resolution measurements of near-surface wind speed and direction over the Gulf Stream region from RADARSAT-2 imagery can be used to reveal the existence of small-scale surface features in the curl and divergence fields of the wind stress. Moreover, as suggested by corresponding AVHRR and MODIS images, evident in the wind stress curl and divergence fields are sea surface temperature front features. By combining the wind stress curl and divergence fields, they are able to provide a predictor for sea surface thermal temperature gradients. The Gulf Stream thermal signature is particularly evident. The importance of this methodology is that SAR can penetrate clouds. A limitation on the method is the use of ancillary data such as QuikSCAT wind directions (no longer available), or other data, to infer SAR-derived wind speeds, or wind stress vectors. BIO is developing the methodology to infer wind stress from the dual-polarization RADARSAT-2 data used in SOIN for high wind-speed cases.

- WP 5 – SOIN compatible Ocean Workstation. MetOc Halifax uses the Ocean Workstation (OWS) to produce their operational Ocean Feature Analysis (OFA) product. A contract was completed that enabled IA Pro-derived SAR ocean features to be ingested into the OWS. SOIN-related computer hardware and software was installed at MetOc Esquimalt, and staff training was conducted on those systems and RADARSAT-2 ordering to integrate the west coast fully into the SOIN project.

- WP 6 (NEW) – West Coast Ocean features. IOS was incorporated into the project to exploit their expertise in chlorophyll and frontal analysis as it applies to SAR imagery. IOS will work closely with ASL Environmental and MetOc Esquimalt when ordering imagery and comparing SAR, thermal IR, and ocean colour imagery results.

- WP 7 (NEW) – SAR Ocean Imaging model. RMC has undertaken the creation and implementation of a SAR ocean imaging model, and is conducting research on inverting the SAR image to determine the underlying ocean surface.

- WP 8 – Statistical analysis of SAR data. Dalhousie University created a statistical logistic regression model that automates the classification of features detected in SAR imagery, allowing for the determination of features associated with thermal fronts. A novel application of statistical methods to the science of oceanography, the model shows promise in providing automated confirmation of thermal features identified in SAR imagery. The model is being integrated into IA Pro.

- WP 9 (NEW) – Acoustical Environmental application. DRDC Atlantic will determine the impact of SAR-identified ocean features on Anti-Submarine Warfare (ASW), in particular the effects of ambient noise calculated from SAR-derived winds and thermal fronts.

Significance: The SOIN project has successfully completed Phase I and all objectives were met. As a result SOIN Phase II is poised to deliver a cutting-edge operational capability to the Canadian Navy.

Future plans: Continue to progress the completion of all WPs and the implementation and operationalization SOIN Phase II through to project completion in March 2013.

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Sommaire

Spaceborne Ocean Intelligence Network: SOIN - fiscal year 10/11 year-end summary

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Introduction: Le projet RSRO a débuté en juin 2007 grâce à un financement de l'Agence spatiale canadienne (ASC) par l'entremise de son Programme d'Initiatives gouvernementales en observation de la Terre (IGOT). Dirigé par le Centre météorologique et océanographique (METOC) de Halifax, le RSRO est un projet de recherche et de développement opérationnel, d'une durée de six ans, qui porte sur l'étude des obstacles à l'élaboration et à la mise en œuvre d'applications océanographiques dérivées des capteurs d'observation de la Terre. Dans le cadre du projet, les METOC de la côte Est et de la côte Ouest sont positionnés pour tirer pleinement parti des capacités de détection de navires en temps quasi-réel (NRTSD) et de détection environnementale en voie de mise en œuvre pour les Forces canadiennes (FC) dans le cadre du projet Polar Epsilon.

Le RSRO se divise en deux phases. La phase I, complétée en mars 2010, a porté sur le développement de produits de pointe appelés à fournir des données sur la visibilité des plongeurs et la température de la surface de la mer, des outils opérationnels, une infrastructure de soutien et une capacité de détection des fronts thermiques, des tourbillons et des limites des masses d'eau au moyen de l'imagerie de radar à synthèse d'ouverture (RSO) RADARSAT-2. La phase II, d'une durée de trois ans et lancée en avril 2010, porte sur la mise en œuvre et l'opérationnalisation des outils du RSRO. Trois nouveaux blocs de travail (BT) ont débuté durant l'exercice 2010-2011, et on a noté l'arrivée de trois nouveaux partenaires – l'Institut des sciences de la mer (ISM) à Victoria (C.-B.), le Collège militaire royal du Canada (CMR) à Kingston (Ont.) et R & D pour la défense Canada – Atlantique (RDDC Atlantique) à Halifax (N.-É.). Le présent rapport donne un résumé des activités et des réalisations du projet pour l'exercice 2010-2011 et du plan de travail pour l'exercice 2011-2012.

Résultats: Outre le BT 1 (gestion de projet, livraison et communication), le RSRO comptait huit blocs de travail en cours durant l'exercice 2010-2011 :

- BT 2 – Système de traitement automatisé. Le METOC de Halifax exploite une version canadienne du système de traitement automatisé de la marine américaine (C-APS) et traite les données des capteurs MODIS, AVHRR et MERIS. À cette fin, les procédures d'ordonnancement des données RADARSAT-2 et d'évitement des conflits (avec le Service canadien des glaces [SCG], R & D pour la défense Canada [RDDC] et le Collège militaire royal du Canada [CMR]) sont bien établies. Le poste de travail océanographique du METOC de Halifax a été mis à niveau pour permettre la réception des fichiers de formes des caractéristiques thermiques dérivées de RADARSAT-2. De plus, l'Institut Maurice-Lamontagne (IML) du ministère des Pêches et Océans (MPO) a terminé les travaux

préparatoires des travaux d'élaboration et de mise en œuvre de climatologie des fronts prévus au cours de l'année qui vient.

- BT 3 – Processeur RSO, outil Image Analyst Pro (IA Pro) et système de planification d'acquisition d'imagerie par satellite commercial (CSIAPS). RDDC Ottawa a installé avec succès et a continué à améliorer les outils logiciels IA Pro et CSIAPS, deux progiciels d'avant-garde utiles à l'acquisition, à l'archivage et à l'évaluation de l'imagerie spatiale. RDDC Ottawa a également mis à niveau, à l'intérieur de l'outil IA Pro, l'outil de détection des éléments océaniques RSO (SOFDT), qui génère de nombreux produits dérivés RSO, y compris des fichiers de formes de caractéristiques dérivés de RADARSAT-2 et de nouveaux produits dérivés de RSO. Une capacité de validation interactive de caractéristiques vectorielles a été mise en œuvre pour aider à la collecte d'attributs de caractéristiques en vue d'analyses statistiques.

- BT 4 – Caractéristiques océaniques déterminées au moyen de SAR. L'Institut océanographique de Bedford (IOB) du MPO continue à étudier les caractéristiques physiques de la couche limite à la mer (MABL) pour établir des méthodes qui en permettraient l'identification, et ses recherches ont donné des résultats intéressants et importants. Notons, en particulier, qu'il a démontré que les mesures de fine résolution prises près de la surface en ce qui concerne la vitesse et la direction du vent dans la région du Gulf Stream à partir de l'imagerie RADARSAT-2 peuvent servir à révéler l'existence de caractéristiques de surface à petite échelle dans le champ de rotation et le champ de divergence de la pression du vent. En outre, comme le laissaient entendre les images correspondantes de l'AVHRR et de MODIS, les caractéristiques du front de température à la surface de la mer sont évidentes dans le champ de rotation et le champ de divergence de la pression du vent. En combinant les champs de divergence et de rotation de la pression du vent, il est possible de fournir un prédicteur des gradients thermiques à la surface de la mer. La signature thermique du Gulf Stream est particulièrement évidente. L'intérêt de cette méthode, c'est que le RSO peut pénétrer dans les nuages. La méthode présente cependant une limite quant à l'utilisation de données accessoires, comme les directions du vent QuikSCAT (elles ne sont plus disponibles), ou d'autres données pour déduire les vitesses du vent dérivées du RSO ou les vecteurs de tension du vent. L'IOB travaille à la mise au point d'une méthode qui permettrait de déduire la tension du vent à partir des données RADARSAT-2 à double polarisation qui servent dans le cadre du RSRO dans le cas du vent à grande vitesse.

- BT 5 – Poste de travail océanique compatible RSRO. Le METOC de Halifax se sert des postes de travail océaniques pour produire ses analyses opérationnelles des caractéristiques océaniques (OFA). Des travaux ont été effectués à contrat en vue de l'intégration, aux postes de travail océaniques, des caractéristiques océaniques SAR dérivées de l'outil IA Pro. Le matériel informatique du RSRO, assorti d'un logiciel, a été installé au METOC d'Esquimalt, et le personnel a reçu la formation requise à l'égard de ces systèmes et de la commande RADARSAT-2, ce qui permettra d'intégrer entièrement la région de l'Ouest au projet RSRO.

- BT 6 (NOUVEAU) – Caractéristiques océaniques de la côte Ouest. On a intégré l'ISM au projet pour tirer parti de ses compétences en étude de la chlorophylle et en analyse frontale appliquées à l'imagerie RSO. L'ISM travaillera en étroite collaboration avec ASL Environmental et le METOC d'Esquimalt au moment de commander des images et de

comparer les résultats en ce qui concerne des images RSO, des images IR thermiques et des images de la couleur de l'océan.

- BT 7 (NOUVEAU) – Modèle d'imagerie RSO de l'océan. Le CMR a entrepris la création et la mise en œuvre d'un modèle d'imagerie RSO de l'océan, et il mène des recherches sur l'inversion d'une image RSO pour déterminer la surface sous-jacente de l'océan.

- BT 8 – Analyse statistique des données RSO. La Dalhousie University a créé un modèle statistique de régression logistique qui automatise la classification des caractéristiques détectées par imagerie RSO, ce qui permet de déterminer les caractéristiques associées aux fronts thermiques. Il s'agit d'une nouvelle application des méthodes statistiques à l'océanographie. Le modèle a été jugé prometteur pour la confirmation automatisée des caractéristiques thermiques identifiées par imagerie RSO. Le modèle est en voie d'intégration à l'outil IA Pro.

- BT 9 (NOUVEAU) – Application environnementale acoustique. RDDC Atlantique déterminera l'incidence des caractéristiques océaniques identifiées par RSO sur la guerre anti-sous-marine (GASM), en particulier les effets du bruit ambiant calculées à partir des fronts thermiques et du vent dérivés de RSO.

Importance: La phase I du projet RSRO a été complétée avec succès, et tous les objectifs ont été atteints. La phase II du projet devrait fournir une capacité opérationnelle de pointe à la Marine canadienne.

Perspectives: Continuer à progresser en vue de l'achèvement de tous les BT et de la mise en œuvre et de l'opérationnalisation de la phase II du projet RSRO par l'achèvement du projet en mars 2013.

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Acknowledgements

1   Introduction

The Spaceborne Ocean Intelligence Network (SOIN) project began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. Led by MetOc Halifax, SOIN is a six-year research and operational development project that addresses barriers to developing and implementing operational oceanographic applications derived from Earth-observation sensors [19], [20]. The SOIN Mission Statement is:

> *To produce next-generation and new environmental products by fusing thermal-IR, multi-spectral and SAR imagery, in operationally-relevant time frames, so as to garner a greater appreciation and understanding of the environmental situation and its impact on operational effectiveness [20].*

The project is positioning MetOc Halifax to take full advantage of Polar Epsilon's Near Real Time Ship Detection (NRTSD) and Environmental Sensing (ES) capabilities that are being implemented for the Canadian Forces (CF) through the Polar Epsilon (PE) Project.

Details concerning SOIN objectives, work packages, milestones, deliverables and due dates were identified in the Phase II project proposal [23], and in prior annual reports [21], [22], [23].

SOIN is divided into two phases. Phase I was completed in March 2010 and focused on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and an ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT-2 (R-2) synthetic aperture radar (SAR) imagery. Phase II kicked off in April 2010 and will focus on the implementation and operationalization of SOIN products. The SOIN project is depicted in Figure 1:

- RSAT-2: R-2 imagery which will be pulled from the PE ftp server that will be located at Aldergrove, BC (starting in 2011) or from the National Earth Observation Data Framework (NEODF) server at the Canada Center for Remote Sensing (CCRS) (as is done currently);

- NWP: Numerical Weather Prediction model outputs will be used as a guide to assist in the detection of ocean features.

- MODIS: Ocean Colour imagery that will be read directly from the PE ES capability;

- AVHRR: Sea surface temperature (SST) imagery from MetOc Halifax's existing L-band dish;

- MERIS: Colour imagery obtained via ftp from the CCRS;

- IA Pro/SOFDT: The DRDC Ottawa-developed Image Analyst Pro/SAR Ocean Feature Detection Tool will automatically extract and classify Ocean Features in SAR ocean imagery.

- C-APS: The Canadian Automated Processing System will produce SST, True Colour, and Diver Visibility products for the SOIN Area of Interest (AOI).
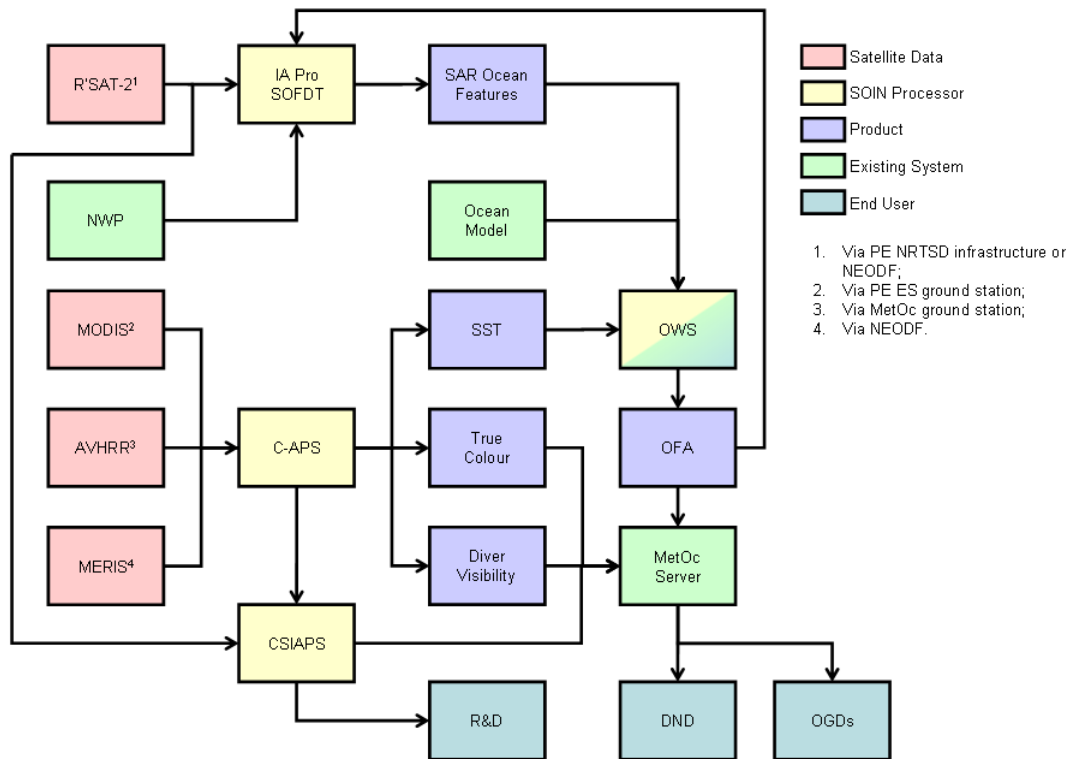
Figure 1 - SOIN schematic representation.

- CSIAPS: The DRDC Ottawa-developed Commercial Satellite Imagery Acquisition Planning System archives all SOIN imagery and C-APS products. The CSIAPS archive will feed R&D activities as well provide an imagery search tool for MetOc clients;

- OWS: The Ocean Workstation that uses Ocean Feature and SST products to produce the Ocean Feature Analysis (OFA); and

- MetOc Server: The MetOc Halifax server that will host SOIN and OFA products for DND users and Other Government Departments (OGDs).

In addition to WP 1 (Project management, delivery, and communications), the active work packages in FY 10/11 were:

- WP 2 – Automated Processing System;

- WP 3 – SAR processor, IA Pro and CSIAPS;

- WP 4 – Ocean features from SAR;

- WP 5 – SOIN compatible Ocean Workstation;

- WP 6 – West coast features;

- WP 7 – SAR ocean image model;

- WP 8 – Statistical analysis of SAR data; and

- WP 9 – Acoustic environment application.

This report provides a summary of SOIN project activities on a work package basis as well as accomplishments in FY 10/11, and the intended work plan for FY 11/12.

2 Work packages

2.1 WP 1. Project management, delivery and communications

2.1.1 Work tasks

The purpose of WP 1 is to manage all aspects of the SOIN project including meetings, deliverables, all written correspondence and reports, and communications. WP 1 is comprised of the following tasks (please note that the Work Task numbers have been revised from the original proposal so as to conform to the current numbering system):

From SOIN Phase I [20] the Work Tasks are:

- WP 1.1 – Organizing and chairing meetings;
- WP 1.2 – Deliverables management;
- WP 1.3 – Port management and Financial plans into Microsoft Project;
- WP 1.4 – Written reports and communications;
- WP 1.5 – Systems management:
- WP 1.5.1 – Operational APS with required thermal data products;
- WP 1.5.2 – SAR METOC automatic processor Version 1.0 (V1.0);
- WP 1.5.3 – 1st interim version of METOC-Pro V1.0;
- WP 1.5.4 – 2nd interim version of METOC-Pro V1.0;
- WP 1.5.5 – MetOc's MODIS X-band ground station integrated with APS;
- WP 1.5.6 – Field-trial version of METOC-Pro V1.0; and
- WP 1.5.7 – METOC-Pro V1.0 delivered.

From the SOIN Phase II proposal [23], in addition to the Work Tasks listed above, WP 1.5 was further modified to include the following sub-tasks:

- WP 1.5 – Systems management (continued):
- WP 1.5.8 – Upgraded Dalhousie University logistic regression model;
- WP 1.5.9 – Project monitoring of RMC and IOS WPs;
- WP 1.5.10 – EO tools implemented in IA Pro;
- WP 1.5.11 – Report on implementation of RMC SAR Imaging Model.

2.1.2 Progress in FY 10/11

WPs 1.1 and 1.2 – Status: In progress.

These two Work Packages are activities that will remain ongoing until the successful completion of the SOIN project.

WP 1.3 – Status: Cancelled.

It was decided to keep all SOIN project documents, WPs and financial plans in MS Office and Excel as these software packages were available to the entire project management team.

WP 1.4 – Status: In progress.

SOIN project partners participated in several conferences and submitted articles for journals based on their SOIN related work. Chris Jones gave an oral presentation on the logisitic regression model for fronts and eddies at the 3rd RADARSAT-2 Workshop held at the CSA in September 2010. Darryl Williams and Paris Vachon presented a SOIN overview poster highlighting the logisitic regression work at the Maritime Rapid Environmental Assessment (MREA) Conference in Lerici, Italy in October 2010. Chris Jones, Paris Vachon, Todd Sikora, and John Wolfe submitted a paper based on SOIN research entitled "Towards automated identification of sea surface temperature front signatures in Radarsat-2 imagery" to the *Journal of Atmospheric and Oceanic Technology* for review. Hailan Li and Will Perrie submitted a paper on SOIN research entitled "On the polarimetric characteristics of convection in the marine atmospheric boundary layer" to the *Geophysical Research Letters* for review. This Work Package will remain ongoing for the length of the SOIN project.

Beyond formal publications, Darryl Williams attended the SAR Applications Working Group (SARAWG) meeting in May 2011, and has participated in the Enhanced Marine Order Coordination (EMOC) process for sorting out RADARSAT 2 ordering conflicts

WP 1.5 – Status: In progress.

WPs 1.5.1 to 1.5.7 are completed, and WPs 1.5.8 to 1.5.11 are underway.

2.1.3   Plan for FY 11/12

All active WPs will continue to be progressed throughout the next FY. In particular, a greater effort will be made to continue communicating SOIN successes to the scientific and operational community.

2.2   WP 2. Automated Processing System

2.2.1   Work tasks

The purpose of WP 2 is to acquire, install, upgrade and integrate the U.S. Navy's Automated Processing System (APS) into MetOc Halifax operations, thereby creating the C-APS, in preparation for exploitation of the Polar Epsilon ES capability. C-APS automatically ingests spaceborne thermal infrared (IR) and multispectral data and produces thermal and water-visibility products required for purposes pertaining to maritime defence and homeland security. WP 2 was comprised of the following tasks:

From SOIN Phase I [20] the Work Tasks were:

- WP 2.1 – Hire MetOc Halifax programmer;

- WP 2.2 – Purchase and install C-APS hardware;WP 2.3 – Staff training on C-APS;

- WP 2.4 – Install C-APS at MetOc Halifax;

- WP 2.5 – Connect MetOc Halifax L-band dish (for AVHRR data reception) to C-APS;

- WP 2.6 – Assess standard C-APS SST product suite to meet client needs – modify as required;

- WP 2.7 – Import MERIS and MODIS offline data and assess resulting C-APS products;

- WP 2.8 – Connect MetOc Halifax X-band dish (for MODIS data reception) to C-APS; and

- WP 2.9 – Conduct frontal climatology analysis for east coast waters.

From the SOIN Phase II proposal [23] the Work Tasks are (please note that the Phase II Work Task numbers have been revised from the original proposal so as to continue from the Phase I Work Task numbering system):

- WP 2.10 – Work Package management;

- WP 2.11 – Calculate climatology of frontal occurrence probability for the East coast using high spatial resolution imagery;

- WP 2.12 – Test the frontal filtering scheme system prior to delivering it to MetOc; and

- WP 2.13 – Implement the frontal filtering scheme into IA Pro.

2.2.2   Progress in FY 10/11

WPs 2.1 to 2.7 – Status: Completed.

WP 2.8 – Status: Completed.

Close cooperation was maintained with the Naval Research Laboratory (NRL) at NASA's Stennis Space Center. The APS software was upgraded to version 4.0.15, and a request for feature enhancement was made to NRL regarding MODIS SST processing which allowed customisation of the MODIS processing SST quality flags and improved SST cloud masking. While preparing the APS for operations on the west coast, a bug was found and reported for passes crossing the International Date Line.

The Polar Epsilon Environmental Sensing X-band receiving antennas for MODIS direct broadcast reception were installed and became operational at MetOc Esquimalt and MetOc Halifax in March and April 2011 respectively. Both systems will feed the APS. MetOc Halifax also installed a new L-band antenna for the direct reception of HRPT AVHRR data.

MetOc Halifax continues to order a significant amount of RADARSAT-2 data, and actively participates in the Enhanced Marine Order Coordination (EMOC) process.

WP 2.9 – Status: In progress.

IML continued to progress the creation of a frontal climatology database for the east coast. In particular, IML regrouped the dataset to generate the frontal climatology, prepared the software for processing, and modified the existing software for efficiency, and testing. The IML remote sensing laboratory developed a large database of SST imagery covering the area-of-interest for the period 1985-2010, and these images can be easily accessed for further processing. The software to process the SST images, extract the area of interest, detect the fronts using the WIMsoft (Windows Image Manager software), and calculate the frontal probability has been successfully tested. Preliminary results indicate that the generation of the SST climatology covering a 10 year period will take approximately 60 days of processing. The generation of a frontal climatology will assist in the classification of fronts and reduce search areas.

WP 2.10 – Status: In progress.

Work package management is an activity that will remain ongoing until the successful completion of WP2.

WPs 2.11 to 2.13 – Status: In progress.

IML will deliver climatological filters to MetOc Halifax in 2011/12.

2.2.3 Plan for FY 11/12

In addition to administering WP 2.10, MetOc Halifax will continue to support all SOIN-related computer architecture and systems, liaise with NRL Stennis on APS issues, support MetOc Esquimalt, and implement the frontal climatology product that IML creates. MetOc Halifax will also remain actively engaged in R-2 data ordering schemes for the project by participating in EMOC discussions, and will interact with and support other SOIN participants with respect to data collection and processing.

2.3 WP 3. SAR processor, IA Pro and CSIAPS

2.3.1 Work tasks

The purpose of WP 3 is to develop, build and install a MetOc SAR processor, and to modify DRDC Ottawa's IA Pro and CSIAPS to produce MetOc-specific versions of these tools. IA Pro is a test bed and demonstration tool that assists in the visual interpretation of remote sensing imagery. It provides capabilities to overlay multiple imagery sources and to locate and visualize target information. CSIAPS includes an imagery archive component. The result of this work package was a MetOc-specific SAR processor, IA Pro and CSIAPS system integrated into MetOc Halifax operations. From SOIN Phase I proposal [20], the Work Tasks are:

- WP 3.1 – Develop approach;
- WP 3.2 – Hire contractors and assign DRDC Ottawa staff;
- WP 3.3 – Recommend hardware for purchase by MetOc Halifax;

- WP 3.4 – Develop SAR automatic processor V1.0 & install at MetOc Halifax;

- WP 3.5 – Upgrade/modify and install IA Pro and CSIAPS data archive at MetOc Halifax;

- WP 3.6 – Produce shapefiles of bathymetric contours at depths of 30, 50, 100, 200, 500, 1000, 2000 metres;

- WP 3.7 – Interim status reviews for SAR-related work (WP 3 & 4);

- WP 3.8 – Develop specifications for the MetOc Halifax version of IA Pro;

- WP 3.9 – Evaluate RADARSAT-2 data within MetOc SAR processor; and

- WP 3.10 – Develop interim and final versions of MetOc-specific version of IA Pro.

From the SOIN Phase II proposal [23], the Work Tasks are (please note that the Phase II Work Task numbers have been revised from the original proposal so as to continue from the Phase I Work Task numbering system):

- WP 3.11 – Work Package management;

- WP 3.12 – Upgrade/modify and provide support for IA Pro and CSIAPS data archive at MetOc Halifax and MetOc Esquimalt;

- WP 3.13 – Improvements to SOFDT; and

- WP 3.14 – Improvements and upgrades to implementation of Dalhousie University statistical logistic regression model.

2.3.2 Progress in FY 10/11

WP3.1 to WP3.9 – Status: Completed.

WP 3.10 - Status: In progress.

IA Pro V2.0.1, available for both Windows and Linux platforms, was provided to SOIN in October 2010. Of note, it boasts of new and improved capabilities such as enhancements to the SAR Ocean Feature Detection Tool (SOFDT), numerous new analysis tools, and an impact assessment of the RADARSAT-2 Maritime Satellite Surveillance Radar (MSSR) [1] mode products that are being implemented by PE.

Enhancements to the current version of SOFDT included implementation of the Dalhousie University SST signature probability model; and the implementation of a statistical capability that buffers detected features and stores them as vector attributes (see Figure 2 and Figure 3).

Newly developed IA Pro V2.0.1 tools include:

- Raster Band Calculation including weighted sum, complex multiplication, square-root of sum of squares, and magnitude and phase operations for SAR single look complex (SLC) images;

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[1] MSSR mode provides for two configurations: 1) OSVN – Ocean Surveillance, Very-wide, Near position, and 2) DWVF – optimized Detection of Vessels, Wide, Far position.

- Stand-alone Canny Edge Detection tool;
- Stand-alone tool with significant functionality for SAR data analysis;
- RADARSAT-2 Distributed Target Analysis tool:
- Improvements to allow transects along-range, across-range, along any arbitrary line, and within polynomial extents;
- KML (raster) export; and
- An impact assessment of the OSVN MSSR mode noise subtracted product (Figure 4).

CSIAPS has also undergone upgrades and improvements including:

- Improved map display using OpenLayers;
- Additional platforms and sensor models such as AIS and Worldview-2;
- Capability to add Terrain files to image acquisition calculations.

WP 3.11 – Status: In progress.

Work package management is an activity that will remain ongoing until the successful completion of WP3.

WPs 3.12 to 3.14 – Status: In progress.

Upgrades will be implemented to address user feedback and new functionality requirements, as they arise.
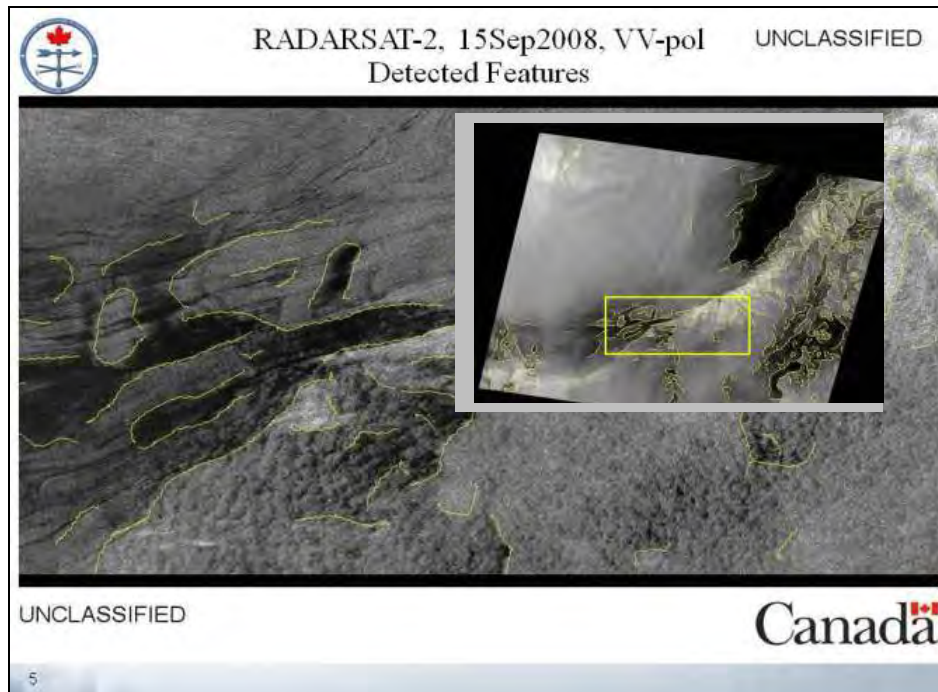
Figure 2 - SOFDT Feature Detection (inset small scale view of image).
Original RADARSAT-2 products © MacDonald, Dettwiler and Associates Ltd. (2010) – All rights reserved.
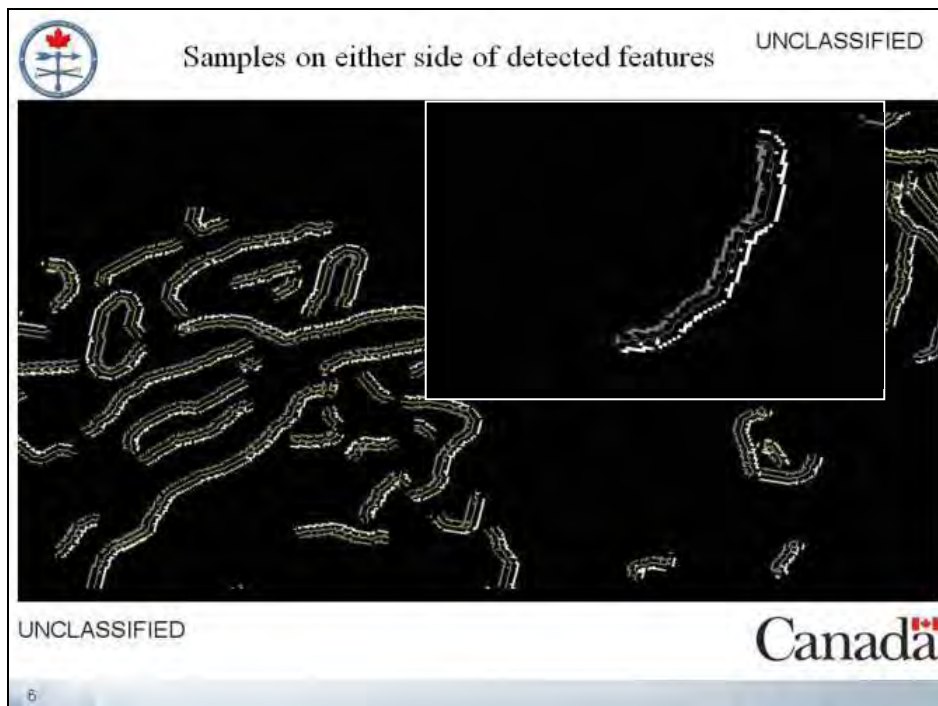
Figure 3 - SOFDT Detected Feature with Buffer (inset large scale image of buffer).
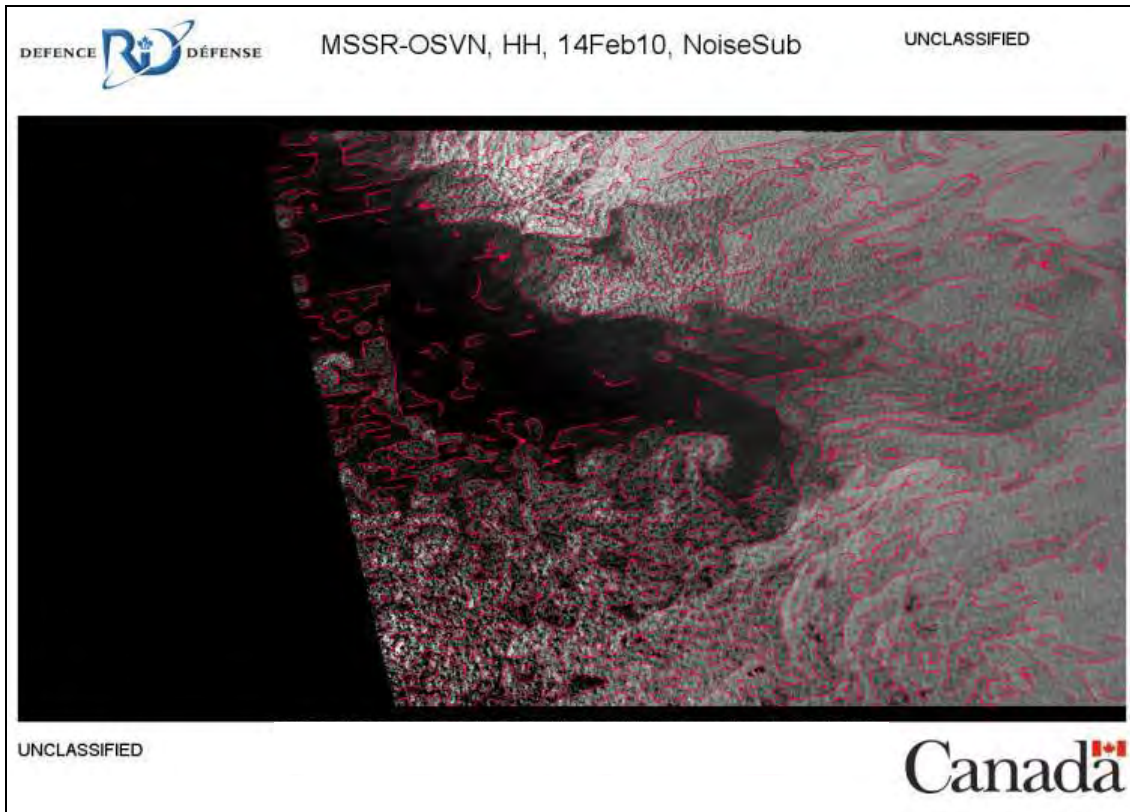
Figure 4 - A noise subtracted scene with vectors overlaid to show identified features. Note that undesirable effects have been mitigated by the noise subtraction operation as evidenced by the lack of horizontal lines (noise floor cusping) being detected.
Original RADARSAT-2 products © MacDonald, Dettwiler and Associates Ltd. (2010) – All rights reserved.

2.3.3   Plans for FY 11/12

WPs 3.10 to 3.14 will continue to be progressed so as to better-meet SOIN requirements, including the implementation of new functionality, software support and bug fixes, and delivery of upgraded versions of the software and documentation.

2.4   WP 4. Ocean features from SAR

2.4.1   Work tasks

The focus of WP 4 is to develop the means to routinely detect the northern wall of the Gulf Stream plus associated eddies and fronts, using spaceborne SAR. From SOIN Phase I [20] proposal, the Work Tasks are:

- WP 4.1 – Develop approach and work plan;

- WP 4.2 – Identify and secure auxiliary data sources;

- WP 4.3 – Order RADARSAT data;

- WP 4.4 – R&D on SST front indicators in SAR that are associated with marine atmospheric boundary layer (MABL) phenomena;

- WP 4.5 – Integrate auxiliary surface current data;

- WP 4.6 – Conduct field trial.

From the SOIN Phase II proposal [23], the Work Tasks are (please note that the Phase II Work Task numbers have been revised from the original proposal so as to continue from the Phase I Work Task numbering system):

- WP 4.7 – Work Package management;

- WP 4.8 – Develop MABL approach & work plan to positively identify meteorological and oceanographic features;

- WP 4.9 – Investigate the use of CODAR surface currents in discerning between meteorological and oceanographic features; and

- WP 4.10 – Integrate auxiliary surface current, SST and meteorological data.

2.4.2   Progress in FY 10/11

WPs 4.1 to 4.6 – Status: Completed.

WP 4.7 – Status: In progress.

Work package management is an activity that will remain ongoing until the successful completion of WP4.

WP 4.8 – Status: In progress.

As a result of SOIN Phase I research, a manuscript [10] is under review by the Journal of Geophysical Research (JGR) for possible publication. The paper looks at a prominent important marine atmospheric boundary layer (MABL) phenomenon, namely convection. Previous spaceborne radar studies have been limited to single polarization data, and therefore their focus was on the variation in intensity of the return radar wave, which was constrained by the existence of a single polarization image pattern, representing different atmospheric and oceanic phenomena. In this paper, the polarimetric characteristics of MABL convection using high-resolution data from fully polarimetric (HH+VV+HV+VH) R-2 images is studied, in conjunction with closely collocated (in time and space) mesoscale atmospheric model simulations, to identify the MABL signals for Mesoscale Cellular Convection (MCC) in the SAR images. To address the SOIN project objective, the BIO analysis also included 641 quad-polarization R-2 SAR images collocated with 52 National Data Buoy Centre (NDBC) buoys, and successfully differentiated the polarimetric SAR parameters associated with MCC from those of other open ocean phenomena based on identifiable polarimetric characteristics.

Figure 5 is characteristic of many ocean SAR images. Areas A, B and C are approximately 10 km in the latitudinal direction, and approximately 5 to 7 km in the longitudinal direction. The

grayscale bar denotes HH return intensity in dBs. The white arrow represents wind direction obtained from QuikSCAT. Interactions with the convective air flow opposite to the ambient wind direction result in a blistered signature which is darker than the background; the blistered signature is brighter than the background when convective air flow is in the direction of ambient wind. Thus, the brighter signal is in the wind direction, and the darker signal in the opposite direction. Numerous examples of this type of blistered backscatter pattern have been seen in SAR images of sea surface, linking them to the MCC [1] in the MABL [2].
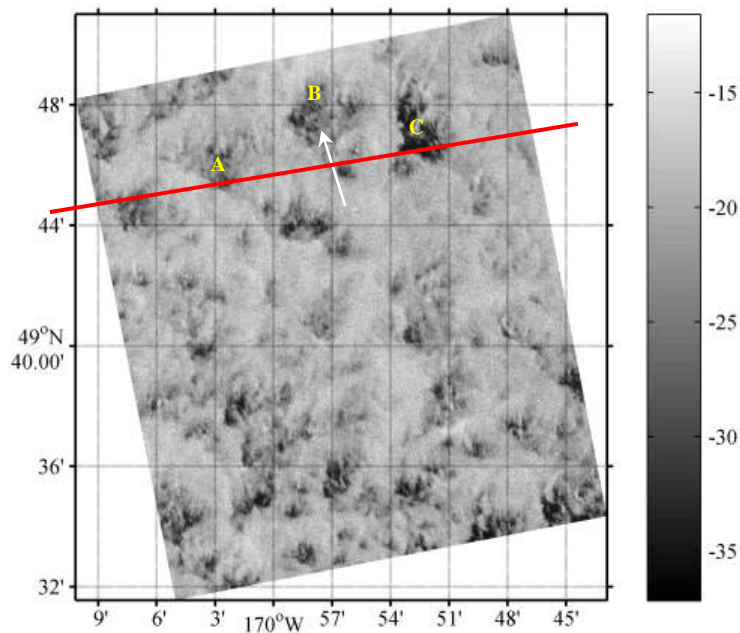
Figure 5 - RADARSAT-2 HH polarization SAR image.

Figure 6 shows the horizontal and vertical distributions of vertical velocity from a WRF (Weather Research and Forecasting model) simulation. In particular, Figure 6 gives the 1000 hPa distribution of vertical velocity, clearly showing upward and downward air motions with maximum speeds reaching 0.15 m/s and -0.25 m/s, respectively. The upward and downward air flow shown in Figure 6 constitutes MCC at the bottom of the atmosphere. Constrained by stability at the upper portion of the MABL (not shown here), the convection does not extend above about 850 hPa, which is consistent with the estimates of 1~3 km [1]. The updrafts and downdrafts correspond well with the light and dark areas in the SAR image (Figure 5). It is notable that although the WRF model simulation is performed independently from the SAR observation, its results reveal the MCC characteristics.
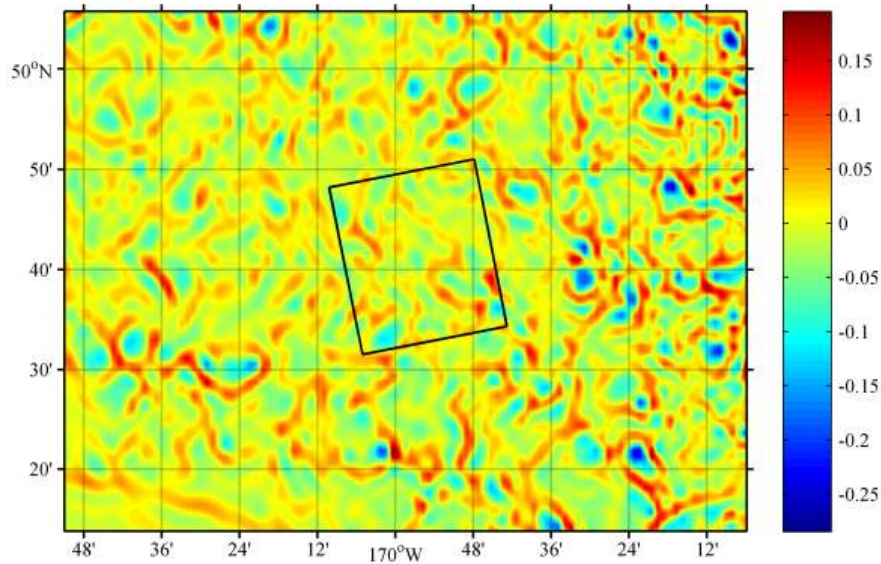
Figure 6 - Vertical velocity (m/s) at 1000 hPa from WRF.

Clearly, the ocean surface is characterized by ocean waves, which undergo continuous variations, and development. Therefore, the Normalized Radar Cross Sections (NRCS) of ocean waves are related to radar frequencies, wind speeds, and incidence and azimuth angles [7] and ocean surface SAR images' polarimetric characteristics are modified by differing image geometry and sea state conditions. These include incident angle, azimuth angle, wind speed, wind direction, significant wave height, wave steepness and wave direction [8], [9], [11], [12], [13].

To compare the polarimetric characteristics of the ocean surface with those of MCC in SAR imagery, BIO used R-2 fine quad-polarization single-look complex data and collocated *in situ* sea state measurements from 52 NDBC buoys during the time period from December 2008 to February 2010. The buoys are located in the Gulf of Alaska, and off the East and West coasts of USA and Gulf of Mexico. The original total number of SAR images is 641, with incidence angles in the range 20.5° to 47.6°, wind speeds, 2 m/s to 26 m/s, significant wave heights, 0.2 m to 8.7 m, wave steepness, 0 to 0.08; these were obtained *after* events with negative air-sea temperature differences were removed in order to avoid instances of atmospheric convection. Missing measurements reduced this number so that the resulting number of SAR images for analysis of the variation of polarimetric characteristics related to wave height is 636; and for wave steepness, to 358; for given significant wave heights and wave steepness, incidence angles are then in the range, 20.5° to 40.8°, and wind speeds, 2 m/s to 19 m/s.

WP 4.9 – Status: cancelled.

The CODAR resources available were insufficient to address their use in discerning between meteorological and oceanographic features. The Canadian Coast Guard was no longer able to support the network of CODARs installed in southwest Nova Scotia, so this aspect of the analysis has been ceased.
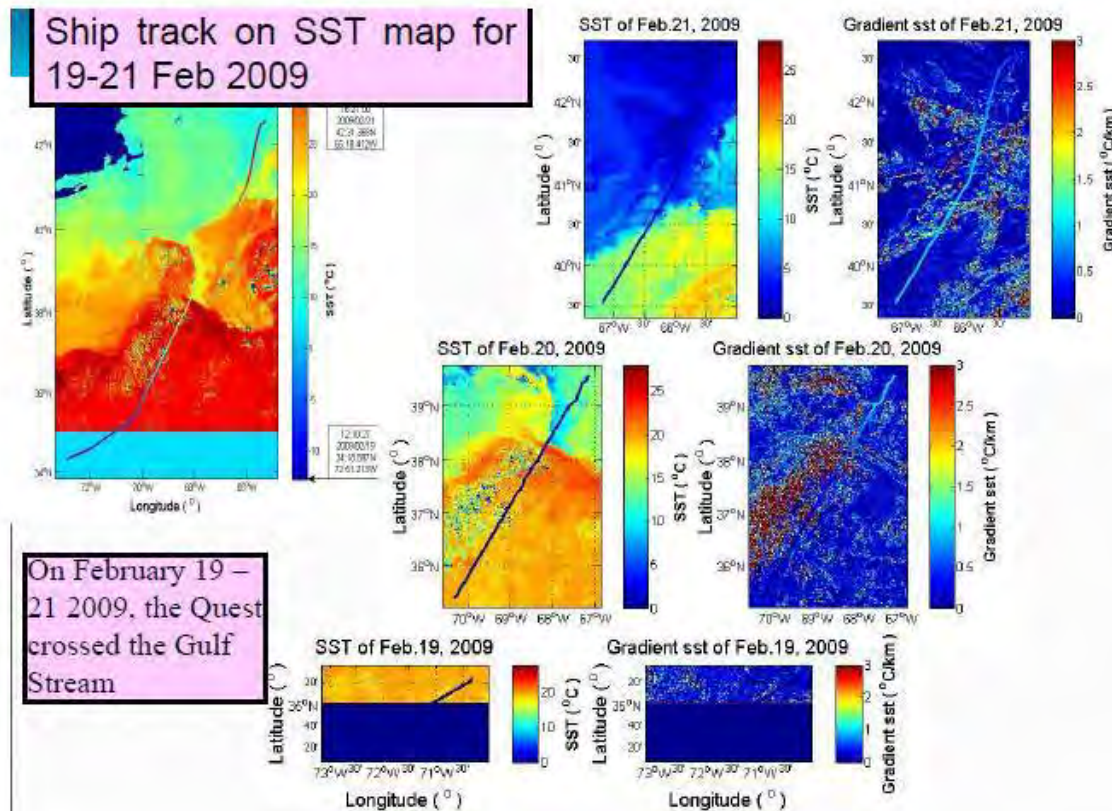
Figure 7 - Quest ship track in February 2009 as it passed through the Gulf Stream.

WP 4.10 – Status: In progress.

CFAV QUEST travelled through the Gulf Stream and collected near surface temperature data. Figure 7 shows the ship's track and the corresponding SST and gradient SST fields. Corresponding wind stress curl and divergence plots are shown in Figure 8, as a function of gradient SST. Clearly the relations among these variables are very noisy. However, it is possible to make correlations among these variables and to derive coefficients. This was not possible using only satellite SAR data and SST data. While this Work Task was not completed in the time available, it is in progress in collaboration with the University of Miami.
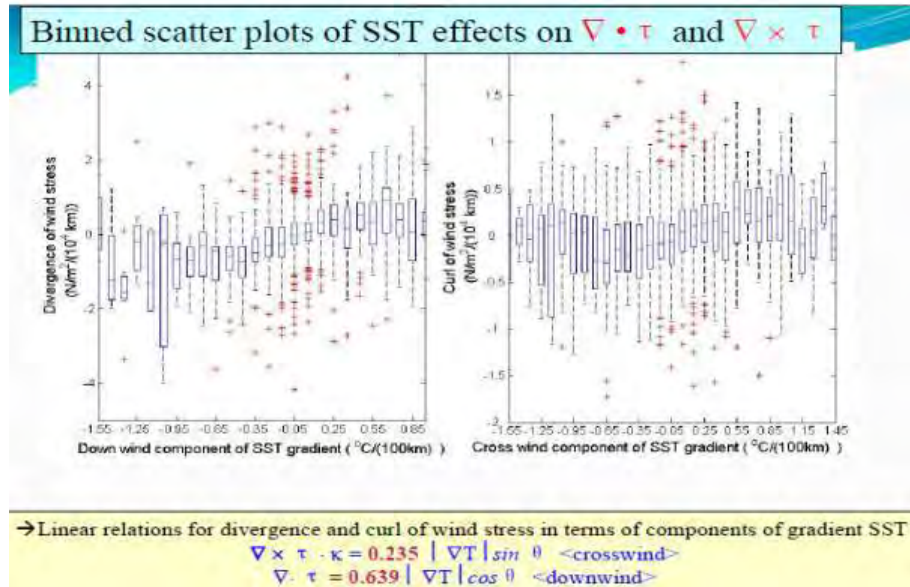
Figure 8 - Coefficients derived relating components of gradient SST to divergence and curl of wind stress.

2.4.3   Plan for FY 2011/12

The specific R&D objectives during the next year are to determine the methodology and auxiliary data required to improve the identification of MABL phenomena and ocean thermal features, such as NWGS, from other processes in SAR imagery; and to recommend analysis procedures that could be used by Canadian operations to automatically detect the NWGS and related fronts and eddies. This will include the provision and delivery of an algorithm using wind stress curl and divergence to determine thermal SST gradients from SAR imagery for integration into IA Pro.

2.5   WP 5. SOIN compatible Ocean Workstation

2.5.1   Work tasks

MetOc Halifax uses the Ocean Workstation (OWS) to produce their operational Sea Surface Temperature (SST) and Ocean Feature Analysis (OFA) product. The OFA is one of MetOc Halifax's primary oceanographic products. It is produced twice weekly (Tuesday and Friday) and provides the ocean conditions (SST and watermass boundaries) within the Maritime Forces Atlantic (MARLANT) Area of Responsibility (AOR). The OFA is used primarily to determine impacts on acoustic propagation for anti-submarine warfare.

The purpose of WP 5 is to integrate MetOc Halifax's existing OWS with SOIN-related data outputs. Work in FY 09/10 had planned to include further development of the OWS to integrate ocean features detected in SAR imagery by IA Pro. From the SOIN Phase I [20] proposal, the Work Tasks are:

- WP 5.1 – Integrate MetOc Halifax auxiliary data from C-APS into the OWS;
- WP 5.2 – Integrate C-APS and SAR processor; and
- WP 5.3 – Staff training.

From the SOIN Phase II proposal [23], the Work Tasks are (please note that the Phase II Work Task numbers have been revised from the original proposal so as to continue from the Phase I Work Task numbering system):

- WP 5.4 – Work Package management;
- WP 5.5 – Automatically ingest RADARSAT-2 fronts and eddies into OFA;
- WP 5.6 – Upgrade OWS software, deliver and install at MetOc Esquimalt;
- WP 5.7 – Conduct staff Training on ingesting RADARSAT-2 features; and
- WP 5.8 – Define best way to represent non-thermal fronts in OFA.

2.5.2   Progress in FY 10/11

WPs 5.1, 5.2, and 5.3 – Status: Completed.

WP 5.4 – Status: In progress.

Work package management is an activity that will remain ongoing until the successful completion of WP5.

WP 5.5 – Status: Completed.

WP 5.5 was completed by the awarding and completion of a contract to JASCO Research Ltd to enable ingestion of IA Pro-derived shape files into the Ocean Workstation. Figure 9 shows the results of SAR-derived fronts. Note that the SAR-derived fronts have no relation to the date of the OFA, and are for demonstration purposes only.

WP 5.6 - Status: Completed.

The Work Task was initiated and conducted through a week-long visit by MetOc Halifax personnel to MetOc Esquimalt to install SOIN-related computer equipment. IA Pro and C-APS were installed, configured, and tested, and MetOc Esquimalt staff was trained in their use and operation. MetOc Esquimalt personnel are also now authorized R-2 users. Training was also conducted on using the APT software and the NEODF website for submitting and downloading R-2 orders.   A west coast SOIN region for ordering R-2 data has been identified, and will be taken into consideration for order de-confliction by the EMOC group. MetOc Esquimalt will cooperate closely with IOS and ASL Environmental in ordering R-2 imagery for use in the SOIN project.

WPs 5.7 and 5.8 – Status: Not yet underway.

2.5.3 Plan for FY 11/12

The main goal for next year is to implement WP 5.7, which is somewhat dependent on results from WP 8. As the automatic detection algorithm improves and evolves within IA Pro, that will give MetOc Halifax a good indication as to the level of operator intervention required to discriminate fronts, and the level of training required will become clearer.
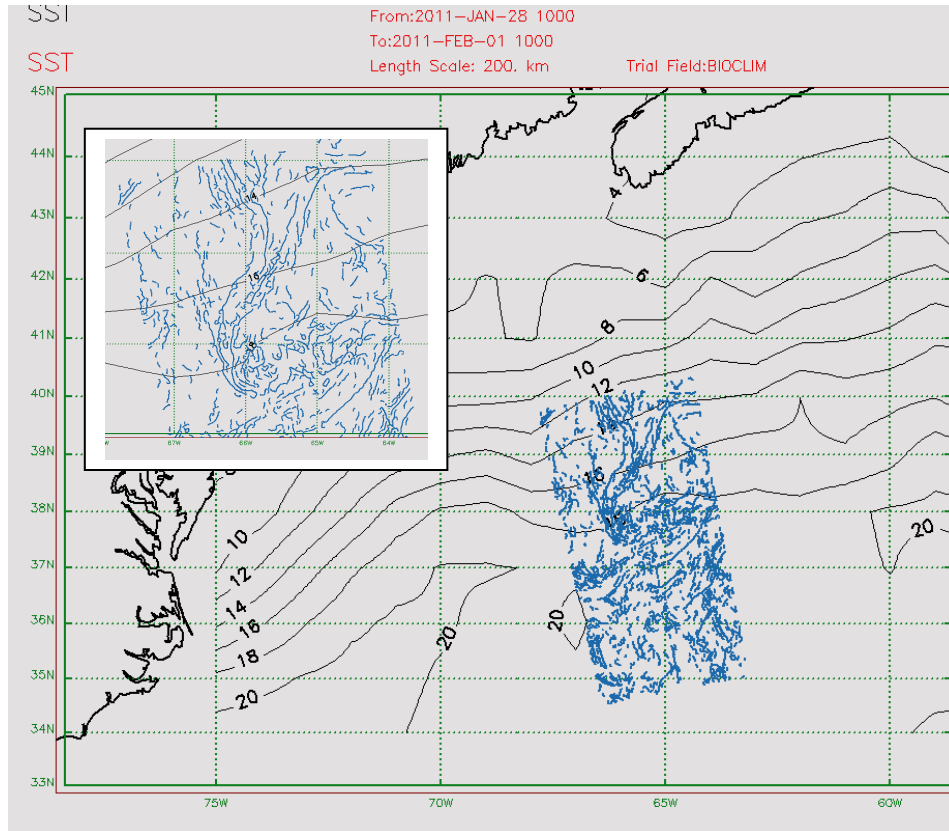
Figure 9 - OFA chart showing overlay of IA Pro generated shape files of canny edges. The time of the R-2 pass and the date of the OFA are unrelated, and for demonstration purposes only (inset is larger scale depiction of canny edges).

2.6 WP 6. West coast ocean features

2.6.1 Work tasks

WP 6 will build upon previous GRIP-funded research carried out at IOS that investigated the use of EO imagery for fisheries and seabird applications on the west coast of Canada. In 2009-10, the group began to examine the detection of ocean frontal features in R-2 imagery, and in 2010-11 they joined the SOIN project to continue their research as part of a Canada-wide initiative. The stated goals of WP 6 include:

- Completion and application of the EO-based biophysical analysis tools begun under previous GRIP projects; and

- Use of IA Pro, along with the "Belkin" and other algorithms, to begin the detection and analyses of ocean fronts and associated chlorophyll signatures off the west coast.

The R-2 detection algorithms will also contribute to a more general initiative to link physical oceanographic features, such as fronts, to biological productivity in British Columbia coastal regions. The new satellite work involves comparisons of thermal and ocean colour fronts against wind conditions on the British Columbia coast in order to determine likely constraints for users of radar products to map ocean fronts in the region. Numerical modeling of the ocean circulation and water property structure being developed for the west coast under separate research programs will eventually be compared to fronts defined by satellite imagery and in situ oceanic data in order to develop a preliminary understanding of the physics of frontal formation off coastal BC. Results will allow for the linkage of observed frontal features to coastal dynamics and biological processes, and provide enhanced tools for frontal detection using colour, thermal, and modeling specific to the BC coast. Through cooperation with DND, DRDC, and the Canadian Ice Service (CIS), frontal mapping R-2 algorithms for operational use will be improved and maps of oceanographic fronts for BC coastal waters produced using radar to supplement thermal and visible EO-based products. SOIN funding will also enable the conduct of studies that relate frontal features to fish productivity statistics and known seabird aggregations for the northeast Pacific. Measurable outcomes include interim and final reports, draft versions of primary scientific manuscripts, algorithms for mapping fronts in SST, colour and radar imagery, maps of seasonal fronts off BC and links to possible oceanic processes, and comparison of frontal variability to fishery and seabird populations for the northeast Pacific.

The first Work Task addresses aspects of previous work that are relevant to the current front detection project, including determination of the background climatology (canonical annual cycle) and possible long term trends in west coast properties as observed in EO imagery. The remaining Work Tasks involve new work related to front detection in west coast R-2 imagery.

From the SOIN Phase II proposal [23], the Work Tasks are:

- WP 6.1 – Report on West Coast oceanography as observed from EO imagery;

- WP 6.2 – Modify IDL code for Belkin O'Reilly algorithm. Install and test IA Pro v2.0.1;

- WP 6.3 – Assemble and process R-2, chlorophyll and SST imagery for analysis; and

- WP 6.4 – Compare fronts in SST, chlorophyll and radar imagery. Determine radar detectability with wind speed and front gradient magnitude.

2.6.2   Progress in FY 10/11

WP 6.1 – Status: In progress.

In order to have a consistent time series spanning the SeaWiFS lifetime (1997-2010), the entire v2010.0 level 3, 8-day dataset was downloaded and recompiled in a "cube" format (latitude x longitude x time). The North Pacific Anadromous Fish Commission (NPAFC) zones dataset was

then regenerated, and the means, canonical annual cycles, trends, and other statistical parameters were recalculated.

A paper entitled "Environmental control of the breeding success of rhinoceros auklets at Triangle Island, British Columbia" has just been published [4] and this study was conducted as part of the ongoing SOIN program. SOIN-funded data products have also been distributed to fisheries biologists at the Pacific Biological Station (Nanaimo) studying the survival of west coast salmon smolts and the survival of juvenile Fraser River sockeye salmon progressing northward through Queen Charlotte Sound. EO imagery is being combined with other physical data available for the northeast Pacific to investigate the role of ocean conditions on the return migration of Early Stewart and Chilko Lake sockeye salmon [18].

The new ocean colour and thermal datasets are now being processed for a possible publication in a peer reviewed journal. Focus is on the background statistical properties (means, variance, and canonical annual cycles), inter-annual variability (including extreme years), and possible long-term climate-scale trends for the west coast of North America, in the region extending from the western Aleutian Islands to central Baja California.

WP 6.2 – Status: In progress.

IA Pro v2.0.2 was installed at the ASL Environmental Sciences offices. Installation difficulties encountered were remedied following modifications to two Python routines. Some memory reallocation was also required in order to run the SAR Ocean Feature Detector Tool. IA Pro v2.0.2 and SOFDT are now installed and successfully running on Windows XP Pro (4 Gb memory), Windows7 32-bit (4 Gb memory), and Windows2 64-bit (8 Gb memory) operating systems.

The Belkin O'Reilly algorithm for front detection [3], currently implemented in IDL and previously used for ocean front detection was modified to reduce edge effects at the data/no-data boundary. This modification, which removed a Gaussian pre-filtering step, resulted in an increase in the extent of valid gradient estimates which is particularly valuable in coastal areas (see Figure 10). Further work is required to remove a residual, 1-pixel wide border of error pixels at the data/no-data boundary.

WP 6.3 – Status: In progress.

New R-2 VV-polarization and MERIS FR chlorophyll datasets for the period April 1 to September 30, 2010 were acquired. R-2 VV-polarization was chosen as it has better retrievals of ocean frontal features than HH- or cross-polarized imagery, and MERIS FR was selected as the EO dataset of choice due to the higher spatial resolution (300 m) than other commonly available datasets (e.g., than MODIS, AVHRR at 1 km resolution). MERIS also has appropriate spectral bands for the calculation of FLH (Fluorescence Line Height), which has been shown to detect chlorophyll through thin cloud.

A total of 24 matching R-2 and MERIS FR datasets were identified within the target time period, and these were ranked for suitability (extent of cloud-free area in the MERIS imagery and the presence of frontal features). Gridded, 6-hourly wind data were obtained from the NOAA North American Regional Reanalysis dataset for the time closest to the R-2 image acquisition. The

wind data was used in interpretation of the results and for input into SOFDT. NASA archives were also searched for coincident (within 1 day) MODIS level 2 SST and chlorophyll imagery. Pre-processing of these datasets is presently underway. There was some delay in obtaining R-2 data since the infrastructure for ordering this imagery for the west coast was not set up within the SOIN project until late February 2011.
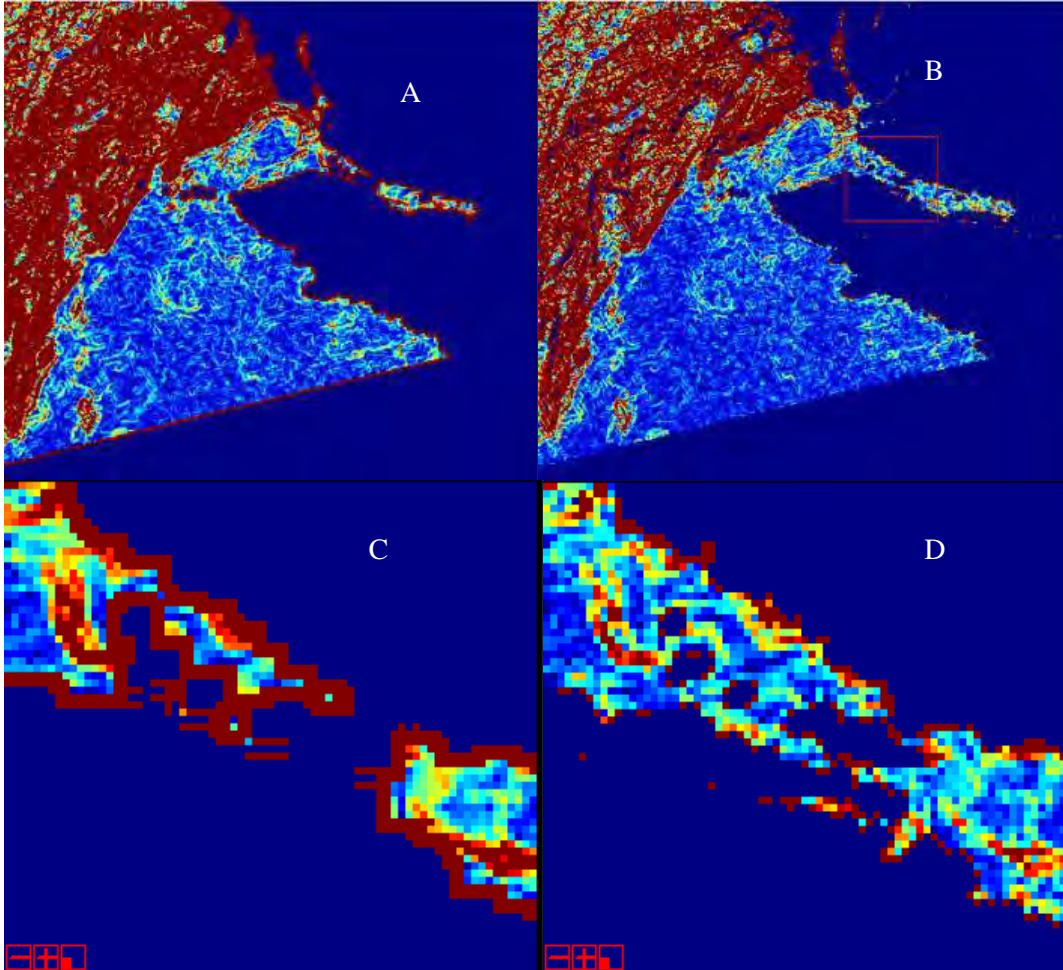
Figure 10 - Belkin O'Reilly [3] code for ocean front detection applied to a MODIS SST image. (A) Gradient image generated from the original code with Gaussian filtering; (B) gradient image produced from the modified code with Gaussian filtering removed; (C) and (D) Close-ups of the region highlighted by the red box in (B).

WP 6.4 – Status: In progress.

This task remains in its early stages. The first two sets of matching R-2/MERIS chlorophyll/MODIS SST scenes are being analyzed to determine whether they support previous observations that the wind speed exceedance threshold for SAR ocean feature detection is lower on the west coast than on the east coast, and should it be, reasonable estimates of west coast thresholds for both wind speed and chlorophyll/SST gradient magnitudes will be developed.

Preliminary observations are shown in Figure 11 and Figure 12. A dark feature (Figure 11, label 1) off southern Vancouver Island in the SAR image co-locates with the seaward extent of a plankton bloom (~3 to 5 mg chl-a m^{-3}) visible in the MERIS image (area in Figure 12 delineated by a bracket). However, another dark feature (Figure 11, label 2) does not correlate with a similar plankton bloom in Figure 12. Canny edge detection algorithms show that the boundaries of the SAR and MERIS features are quite different, and although a 4.4 h offset in acquisition times may account for some of the difference, the boundaries of the SAR features may have more to do with gradients in wind speed than ocean features.
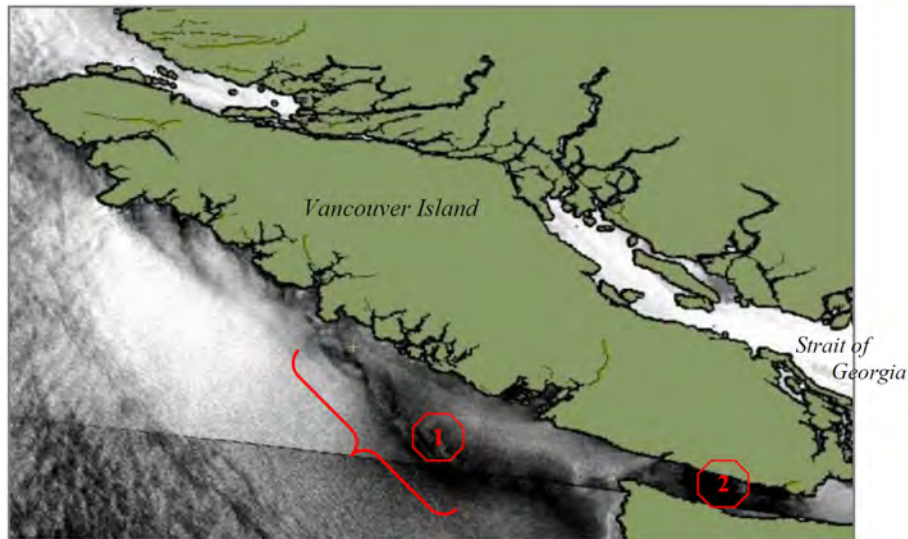
Figure 11 - RADARSAT-2 image for 16 June 2010.
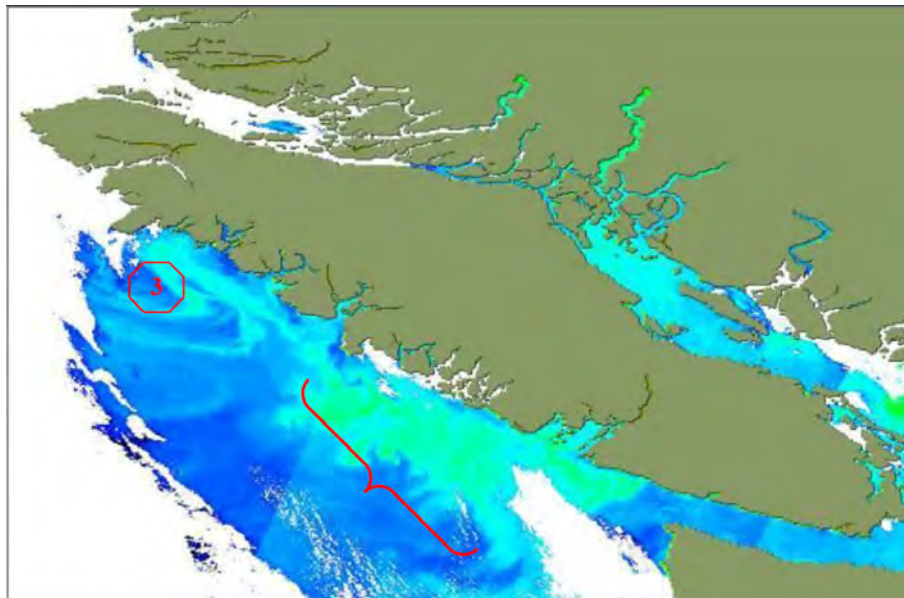
Figure 12 - MERIS chlorophyll image for16 June 2010.

2.6.3   Plan for FY 11/12

Measurable outcomes will include interim and final reports, and draft versions of primary scientific manuscripts pertaining to:

- Algorithms for detecting and mapping fronts in SST, colour and radar imagery;

- Maps of possible seasonal fronts off the British Columbia coast and links to oceanic processes; and

- Comparison of frontal variability to seabird survival and to fish migration and production in the northeast Pacific.

2.7   WP 7. SAR ocean imaging model

2.7.1   Work tasks

WP 7 will modify and implement an existing numerical SAR Ocean Imaging Model describing the interaction of SAR signals with the ocean surface. The model will assess the effects of ocean surface conditions (temperature, winds, currents, waves) on SAR imagery, and provide estimates of these parameters from SAR imagery". Funding was not available to RMC until late in Q3. While this delayed the start of the WPs, through RMC 'contributions in kind', work has commenced. From the SOIN Phase II proposal [23], the Work Tasks are:

- WP 7.1 – Work Package management;

- WP 7.2 – Conduct a survey of existing SAR models;

- WP 7.3 – Acquire the agreed-to SAR model;

- WP 7.4 – Install, modify and validate the forward model;

- WP 7.5 – Develop and validate the inverse model; and

- WP 7.6 – Provide a way-ahead plan for integration of the SAR Ocean Imaging Model into SOIN operations.

Components of WP 7.2, 7.3 and the first part of WP 7.4 were scheduled to be complete in FY 10/11.

2.7.2   Progress for FY 10/11

WP 7.1 – Status: In progress.

Work package management is an activity that will remain ongoing until the successful completion of WP7.

WP 7.2 – Status: In progress.

The search for an existing SAR model is underway. Advice was sought internationally at both the International Geoscience and Remote Sensing Symposium in Honolulu, HI, August 2010, and

the 5th International Workshop on Applications of SAR Polarimetry and Polarimetric Interferometry, (Polinsar), European Space Agency Research Institute, Frascati, Italy, January 2011. A highly qualified person, a numerical modeller, was identified for the position and was hired in December 2010. He is currently conducting a literature review of existing models and methodology. For the purposes of running the model, access to the High Performance Virtual Computing Laboratory (HPCVL) was secured.

WP 7.3 – Status: In progress.

Selection of a suitable model should be completed early in Q1 FY 11/12. Acquisition of the model code should proceed quickly from there, and be completed before the end of the second quarter.

WP 7.4 – Status: Not yet underway.

Completion of Work Task 7.4 is expected to take two quarters, and therefore will be completed by the end of FY 11/12.

WP 7.5 – Status: Not yet underway.

WP 7.6 – Status: Not yet underway.

2.7.3   Plan for FY 11/12

The main goal for the upcoming year is to determine which SAR model is most appropriate to use, and commence implementation. Once that stage is completed, WP 7.4 and 7.5 will progress quickly.

2.8   WP 8. Statistical analysis of SAR data

2.8.1   Work tasks

The objective of WP 8 is to refine the probabilistic model used to identify features detected by IA Pro's Canny edge detector as signature of one of the following classes of phenomena: SST front and/or North Wall of the Gulf Stream, atmospheric front, eddy or ring. From the SOIN Phase I proposal [20], the Work Tasks are:

- WP 8.1 – Work Package management;
- WP 8.2 – Apply logistic regression model to SAR Gulf Stream rings, ocean eddies, smaller thermal fronts;
- WP 8.3 – Investigate application of logistic regression model to positive identification of chlorophyll in EO images;
- WP 8.4 – Continue to refine and adjust parameters as more data become available.

From the SOIN Phase II proposal [23], the Work Tasks are (please note that the Phase II Work Task numbers have been revised from the original proposal so as to continue from the Phase I Work Task numbering system):

- WP 8.5 – Make a comparison of the GSNW Search Region and the estimated location of the GSNW from OFA (Ocean Features Analysis) data supplied by MetOc Halifax;

- WP 8.6 – Collect a set of feature vectors from SAR/SST image pairs on an ongoing basis from which to develop a statistical model;

- WP 8.7 – Consult with DRDC Ottawa on ways to automate the identification of features that correspond to SST fronts using R-2/SST image pairs;

- WP 8.8 – Investigate a variety of statistical models to identify the best approach to feature identification;

- WP 8.9 – Consult with DRDC to produce an objective classification algorithm for feature vectors that can be implemented in IA Pro;

- WP 8.10 – Working with the team on the West Coast, collect data from R-2/Ocean Color pairs to build a classification algorithm based upon Ocean Color;

- WP 8.11 – Document the modified version of the speckle reduction algorithm and forward to DRDC Ottawa and to RMC;

- WP 8.12 – Train on how to recognize the signatures of various atmospheric and oceanographic processes in R-2 imagery;

- WP 8.13 – Determine the feasibility of collecting and analyzing all data (SAR, SST, Ocean Color and Winds) for all of the SOIN project R-2 images by estimating the rate at which images can be processed;

- WP 8.14 – If feasible, collect and tabulate the data;

- WP 8.15 – As this data are tabulated, begin tabulating concurrent weather information from EC GEM regional model data collected by MetOc Halifax;

- WP 8.16 – Investigate measures of texture in R-2 imagery and ways to compare and classify textures;

- WP 8.17 – Complete a draft of a paper for peer review and journal submission to include documentation of work accomplished to date; and

- WP 8.18 – Recollect labelled feature vectors for a second try at the logistic regression classifier.

2.8.2   Progress in FY 10/11

WP 8.1 – Status: In progress.

Work package management is an activity that will remain ongoing until the successful completion of WP 8.

WPs 8.2 to 8.4 – Status: Completed.

WP 8.5 – Status: Completed.

The estimated location of the GSNW from the OFA data supplied by MetOc Halifax, covering the period from January to June 2009, appears as an ensemble of blue lines in Figure 13. The red lines enclosing what is defined to be the Gulf Stream North Wall Search Region (GSNWSR), were determined by a statistical analysis of HYCOM sea-surface height anomaly (SSH) data [19]. A comparison of the bounds of the GSNWSR and the OFA ensemble reveals a difference in mean and variability:

- To the east of about 68°W, the mean of the OFA ensemble is shifted southward compared to the bounds of the GSNWSR. It's possible that using SSH anomaly as a proxy for the location of the GSNW biases the results northward. If this incongruity were deemed to be significant, a simple correction would be to move the southern bound of the GSNWSR about 2 degrees to the south; and
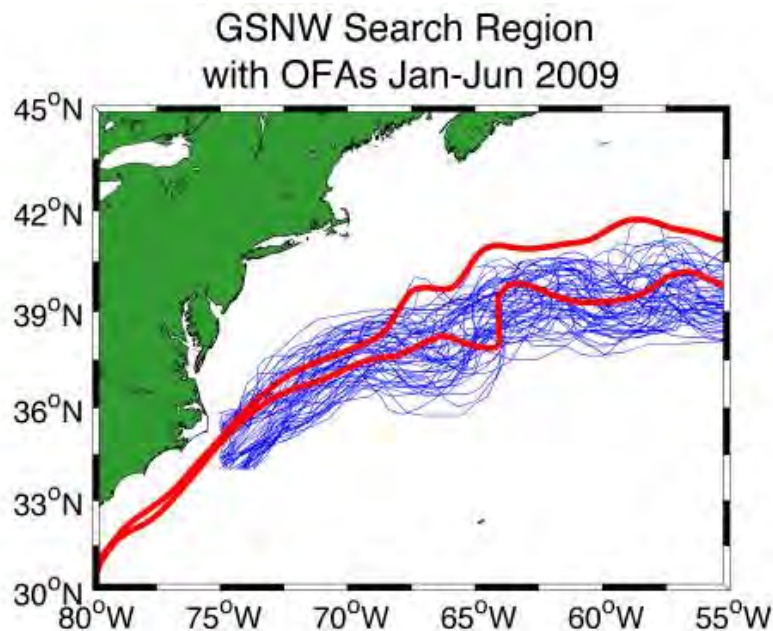
Figure 13 - A comparison of the location of the Gulf Stream North Wall (GSNW) as determined by a statistical analysis of HYCOM SSH anomalies (red envelope) with fronts identified in the MetOc Halifax OFA (blue).

- Variability in the path of the Gulf Stream is known to increase significantly starting at 68°W, as bathymetric constraints are relaxed and baroclinic instabilities become more energetic. This regime shift is represented in the GSNWSR where it widens markedly at about the same longitude, but is not seen in the ensemble of OFA fronts, which is constant in variability along its entire length. As the OFA ensemble contradicts the well-documented increase in variability stating at 68°W, this discrepancy warrants investigation.

Although the location of a Canny edge with respect to the GSNWSR (inside or outside), identified by IA Pro's ocean feature detection stream, has been shown to inform the probability that the Canny edge is the signature of an SST front [Jones et al., manuscript submitted], the

information content is not sufficient to be of practical use. It was suggested at the semi-annual meeting in December 2010 that its distance from the most recent OFA replace the location of a Canny edge inside or outside the GSNWSR. This is a good approach as it represents the utilization of a priori knowledge of the location of the GSNW to give an informed initial guess. As our ability to identify SST front signatures in SAR imagery improves, this information fed into the OFA will in turn improve the initial guess, potentially resulting in marked reduction in errors in the OFA.

WP 8.6 – Status: In progress.

Upon completion of changes made to IA Pro's target analysis module, additional feature vectors were collected in late November of 2010. To investigate the possibility of utilizing an unsupervised classification algorithm, a large number of feature vectors were collected, with no restriction on their length (past analysis used only Canny edges more than 70 pixels in length to make manageable validation by comparison with concurrent SST imagery), but without collecting validation data. A total of 8644 feature vectors were collected from 16 R-2 images. A range of classification techniques were tried on the entire feature vector space and its subspaces, including k-means, discriminant analysis, and principal component analysis. The feature vectors proved to be inseparable in every case, indicating that unsupervised classification is not a promising approach.

Case studies are being conducted on coincident SAR and SST data on an ongoing basis with the idea of constructing a database of oceanographic and atmospheric signatures in SAR images for future studies. This activity has had the benefit of making the analyst more familiar with common structures in the Gulf Stream, and with the interactions between SST, winds and SAR backscatter. As a consequence, it is expected that the quality of feature vector validation will be much improved, which in turn can be anticipated to result in an improved classification algorithm. A new set of validated feature vectors will be collected from the growing set of case studies as soon as a modification in IA Pro that computes the distance of each Canny edge from the location GSNW as determined by the most recent OFA has been completed.

WP 8.7 – Status: In progress.

Automated validation of feature vectors was suggested to reduce potential bias introduced by manual validation. For example, the analyst may unconsciously disregard Canny edges that are SST front signatures when the edges are small, thus biasing the statistical analysis to favour longer SST front signatures. Automation of this process is, however, a nontrivial challenge, that may well require a lot of time and effort for marginal gains. Furthermore, the growing collection of well-validated SST front signatures in SAR images, resulting from case studies, negates the need for automation. It is therefore suggested that automated validation be set aside in favour of more time spent on case studies. Further work on WP 8.7 is, therefore, cancelled.

WP 8.8 – Status: Completed

An approach to image segmentation that is more comprehensive than the dichotomous classification algorithm used thus far was investigated. The processes that result in manually identifiable signatures in SAR images may be categorized as follows:

- Pure Atmospheric Processes – Horizontal and vertical modes of atmospheric oscillation that occur independently of SST and impact the ocean's surface;

- Pure Oceanographic Processes – Horizontal and vertical modes of oscillation in the water column that impact the ocean's surface, including internal waves, current shear, Kelvin-Helmholtz instability waves, cold water upwelling, and oscillations in phytoplankton biomass, which acts as a tracer for surface currents;

- Coupled Processes – Small-scale modes of oscillation in the MABL that impact the ocean's surface, consisting primarily of processes forced by ocean-to-atmosphere heat flux; and

- Anthropogenic Processes – Ships, ship wakes and anthropogenic surfactants create signatures in SAR imagery, but are generally ignored, as they are small-scale compared to the oceanic processes of interest.

The objective was to classify signatures in SAR images corresponding to processes from the first three categories. The difficulty, as demonstrated in the case study is that many of these processes look similar to one another, at least to the Canny edge detector combined with the logistic regression classification algorithm currently in IA Pro's SOFDT.

The location of an SST front determined using an SST image can inform the classification algorithm by its location, shape and orientation compared to Canny edges or texture boundaries. This is similar to the use of OFA derived SST fronts mentioned above. Monthly climatology of quasi-stable components of the Gulf Stream, which is an extension of the idea of producing the GSNWSR Figure 13, may also assist in identifying where the GSNWSR might be expected to be found in future imagery. This may include identification of annual and inter-annual modes of oscillation in the Gulf Steam and in other SST fronts associated with the Gulf Stream. To explore these ideas, it may be helpful to confine the analysis to regions of the Gulf Stream that are relatively stable, for example; in the region between Cape Hatteras and 68°W and as far north as Cape Cod.

WP 8.9 – Status: Completed.

The current logistic regression classification algorithm has been implemented in IA Pro.

WP 8.10 – Status: Not yet underway.

An opportunity to work with the West Coast team has not yet arisen. However, while compiling case studies, ocean color in the form of estimates of chlorophyll-a obtained from MODIS Aqua and Terra have been utilized, when available, and have been found to be very useful in determining the location of the Gulf Stream. An example appears in Figure 14, in which the GSNW (as well as the south wall of the Gulf Stream) is apparent as a sharp chlorophyll-a concentration gradient.
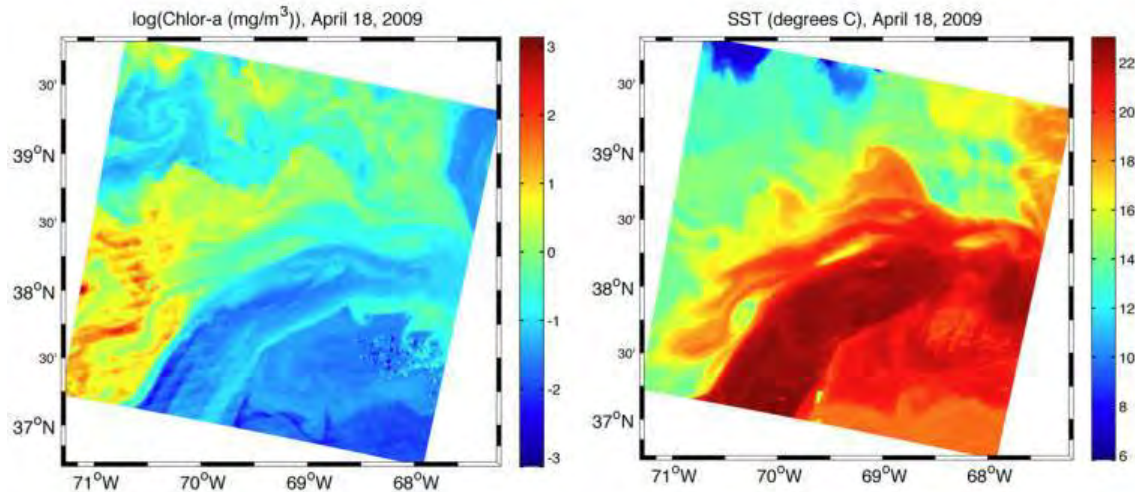
Figure 14 - The north and south walls of the Gulf Stream are readily identifiable in this ocean color image (MODIS chlorophyll-a) and SST image.

The warm water of the Gulf Stream, because it is less dense than colder water at depth, is decoupled from the nutrient rich ocean bottom. As a result, it is highly oligotrophic and cannot sustain high concentrations of phytoplankton. Waters on the shelfward side of the Gulf Stream are highly eutrophic because of relatively shallow depth and frequent vertical mixing. During the spring and autumn, phytoplankton blooms produce very high concentrations of biomass at the ocean's surface, which are identifiable by the effect they have on the color of the ocean as seen from space. SST and ocean color fronts are therefore frequently coincident along the GSNW. Furthermore, phytoplankton biomass acts as an excellent tracer of ocean currents, and can make visible subtle patterns in current shear that often cannot be seen in SST imagery. Eddies are often apparent in SAR imagery only because of the presence of biomass. It is therefore possible to replace SST with ocean color images to validate feature vectors and train a classification algorithm for the west coast data, provided that an analogous SST-ocean color correlation occurs.

WP 8.11 – Status: Completed.

A documented version of a naïve speckle reduction algorithm was prepared and passed on to other members of the team.

WP 8.12 – Status: Completed.

A great effort was made to compile as much material as possible in an effort to learn how to accurately identify atmospheric signatures in SAR images. Efficiency in the accurate identification of atmospheric and oceanographic signatures in SAR images has been attained. A growing set of case studies have been developed to allow feedback from other experts on the team. An ongoing effort will be made to improve understanding of atmospheric processes and their effects upon SAR images.

WP 8.13 – Status: Completed.

Given the availability of SAR, SST and wind data, the identification of oceanographic and atmospheric signatures requires 15 to 20 minutes per SAR image (i.e., per case study). It is estimated that a minimum of about 100 case studies would be sufficient to provide good representation of signatures produced by pure atmospheric, pure oceanographic and coupled processes, which would require no more than about 35 hours. Collection of the necessary data would require approximately 5 days working at the IA Pro station at MetOc Halifax. It is therefore deemed to be feasible to build such a database of case studies.

Note that MODIS SST data is currently provided as a maximum pixel composite. There are cases where single MODIS granules (or AVHRR swaths) are more informative and facilitate more accurate signature identification than a composite image. For this reason, SST imagery should be provided as a set of individual granules in addition to composite form. Note that MODIS ocean color images (i.e., chlorophyll-a concentration) should be included in the data for each case study (as single granules and in composite form) to enable validation of signatures of surfactant concentrations when they are identified in SAR images.

An investigation in the addition of GEM data to case studies is currently in its early stage. Of particular interest is to relate a measure of the stability of the MABL with SAR brightness or measures of texture in SAR imagery. Progress in this requires further collaboration with other team members and an assessment on the availability of the GEM data.

The experience gained from case studies is anticipated to enable accurate identification of features in all RADARSAT-2 images in our archive that do not have coincident SST imagery for validation. It is estimated that the analysis of such images, after a sufficient number of case studies have been completed (i.e., about 100), will take about 10 minutes per image. It would therefore be feasible to process in the order of 100 such images per week.

WP 8.14 – Status: Completed.

A suite of Matlab™ function has been written to facilitate the identification of signatures in SAR images validated by coincident SST, QuikSCAT winds and ocean color data. This code has been used to generate a set of case studies, each consisting of several slides. The first slide in each case study is a synopsis, with the SAR image marked up, an example of which appears in Figure 15.

The remaining slides provide all of the images necessary to validate features identified on the SAR image. The synopsis page has been designed to provide all relevant information in a consistent form and in one place to facilitate the transfer of the information into a spreadsheet or database. Case studies are currently being collected on the SOIN SharePoint site.

WP 8.15 – Status: In progress.

Code is currently being prepared to make use of GEM data collected by MetOc Halifax. Discussion with other team members is required to determine the exact set of parameters that are to be collected.

SAR 20090307 222713

data field	source	date	time
SAR	RADARSAT-2	2009-03-07	22:27:13 UTC
SST	MODIS L2 Composite	2009-03-07	1330-1900 UTC
Winds	QuikSCAT L3	2009-03-07	Descending ~2200-2300 GMT
CHL	n/a	n/a	n/a

Synopsis:

QS Winds 2-14 m/s
SAR Winds 2-25 m/s
Max SST Gradient – 10-14 degrees C
GSNW visibility: good to excellent
Weather front signatures: several

Atmospheric features: high pressure system to the south, a cold front to the north.

SST-Wind coupling: n/a

(a) Current shear along the GSNW.
(b) Surfactant concentrated by current shear along the GSNW.
(c) Low backscatter over water colder than the Gulf Stream.
(d) Warm front.
(e) Band of rain cells.
(f) Frontal wind shear.
(g) Convective rolls.

Figure 15 - The synopsis page for a case study.

WP 8.16 – Status: In progress.

Image segmentation by textural measures has been investigated in some detail. This has included investigation of methods currently documented in the literature as well as the development of novel methods tailored specifically to ocean feature detection and identification. Although still in progress, the search for suitable textual measures has been greatly aided by the experience gained in case study analysis, which has revealed a set of commonly occurring textural elements.

WP 8.17 – Status: Completed.

A paper describing progress in automated ocean feature detection has been submitted to the Journal of Atmospheric and Oceanic Technology.

WP 8.18 – Status: Not yet underway.

Collection of a second set of labeled feature vectors for training the logistic regression classifier is pending modifications to IA Pro by DRDC Ottawa.

2.8.3   Plan for FY 11/12

The logistic regression model constructed to identify SST front signatures in SAR imagery has thus far proven to be relatively inaccurate in discriminating between SST front and certain atmospheric front signatures. Preliminary investigations have shown that the projection of SAR

derived winds onto a curvilinear coordinate system centered on the signature of a frontal process identified by a Canny edge detector is a promising way to discriminate between SST front and synoptic scale atmospheric front signatures, and that a similar framework can be used to identify signatures of processes such as current shear, atmospheric gravity waves and oceanic internal waves. In addition, texture analysis may be a promising method to discriminate between signatures of areal processes, such as surfactant dampening or convection. The main objective for the next fiscal year will be to develop a more sophisticated model for SAR ocean feature classification based upon these techniques.

2.9 WP 9. Acoustic environment application

2.9.1 Work tasks

WP 9 will determine the extent to which SAR-derived thermal features and winds can be used to characterize the acoustic conditions for naval sonar operations. From the SOIN Phase II proposal [23], the Work Tasks are:

- WP 9.1 – Collect in situ meteorological, oceanographic, and acoustic data in the SOIN study area on a non-interfering basis during other DRDC R&D activities involving CFAV QUEST;

- WP 9.2 – Predict underwater acoustic ambient noise levels using SAR-derived wind fields; and

- WP 9.3 – Predict underwater acoustic transmission loss through thermal fronts detected in SAR imagery.

2.9.2 Progress in FY 10/11

WP 9.1 – Status: In progress.

Meteorological, oceanographic, and acoustic data were collected during two DRDC Atlantic sea trials involving CFAV QUEST. The first trial, designated Q316, took place in September and October of 2008, with the data for this work package acquired 15-17 Sep 2008, in the Northeast Channel and Brown's Bank area (42.30ºN, 65.50ºW). The second trial, designated Q325, took place in the Emerald Basin and Emerald Bank area (43.75ºN, 62.75ºW) in October and November of 2009. In both cases, an acoustic source was towed along a straight-line track 30-40 km in length, and moored acoustic receivers were used to monitor the received sound pressure level. Acoustic transmission loss (TL), the difference between transmitted source level and received sound pressure level, depends in a complicated way on ocean sound speed profiles and bottom composition. Variations in ocean properties (temperature, salinity) on which sound speed profiles depend can therefore strongly affect measured TL. During the TL experiments, sound speed profiles and conductivity-temperature-depth (CTD) profiles were acquired for use as inputs to models capable of predicting TL for comparison with measurements. The data acquired were analyzed during FY 10/11 in support of WP 9.3 and 9.4 as described in the following sections.

WP 9.2 – Status: In progress.

Underwater ambient noise levels were collected during the Q316 and Q325 sea trials. During Q316, three sets of ambient noise data were collected during periods that coincided with the acquisition of R-2 imagery, on the 16th, 17th, and 18th of September. During Q325, ambient noise data were acquired coincidentally with R-2 imagery on only one occasion (the 5th of November), although a second set of ambient noise data was collected on October 31st, 12 hours after a SAR image was collected. Wind speed data were also collected during both trials using ship-borne instruments and deployed sensors. Wind speeds were computed from the SAR data by Halifax MetOc and used to model ambient noise levels, which were then compared to the measured ambient noise. This process and the results thereof are described elsewhere [14], [15], and are summarized here.

Figure 16 shows a comparison of wind speeds derived from the R-2 images versus wind speeds as measured on the instruments (all adjusted to a 10 m height using a logarithmic wind speed vs. height profile). The wind speed obtained from the GoMoos buoy was an hourly average. The wind speed measurements with the DRDC met buoy were made every 2 minutes, and the mean and standard deviation were computed over one hour of measurements (centred on the R-2 image acquisition time). The wind speed measurements acquired aboard the CFAV QUEST were made every minute, and again the mean and standard deviation were computed over one hour of measurements. In the cases where R-2 images were acquired in a location where CFAV QUEST was operating, CFAV QUEST was typically travelling at about 5 knots. Wind speed readings were taken from the NADAS feed from the port-side anemometer, adjusted to a true wind speed based on the ship speed and heading. The starboard anemometer was not functional. The mean and standard deviation of the wind speeds for the R-2 estimates were taken from the wind speeds in a 10-km radius around the location of each instrument.
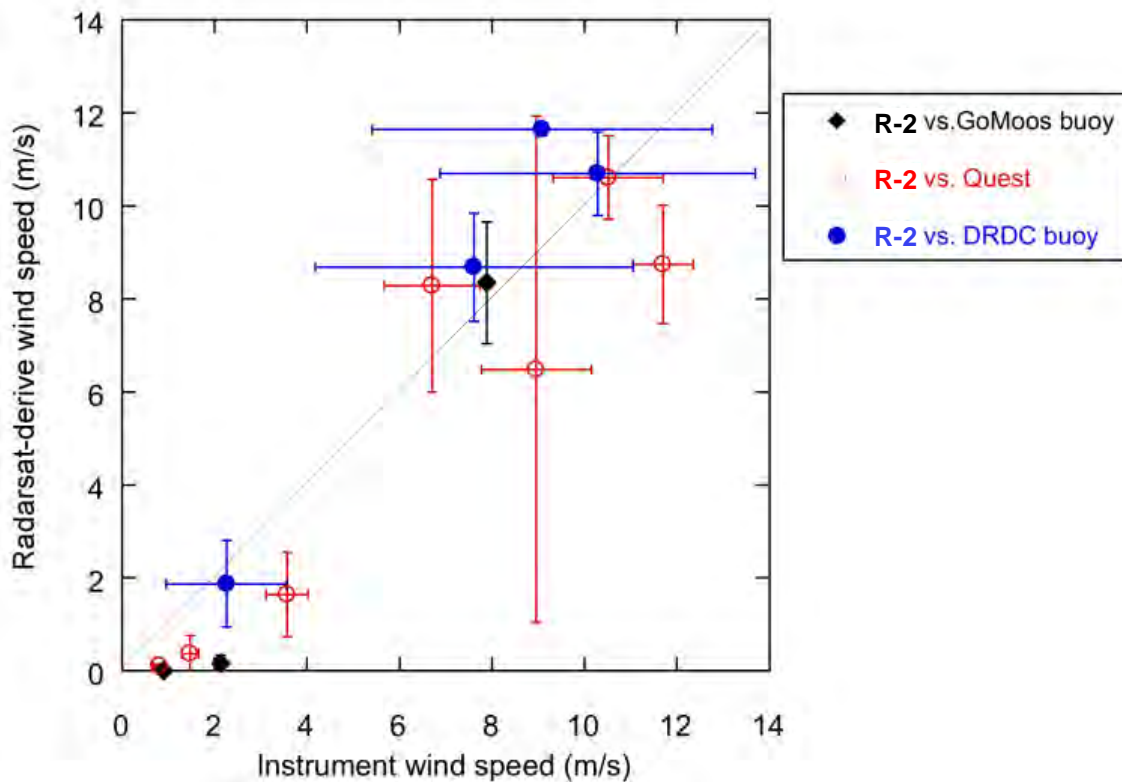
Figure 16 - Comparison of R-2-derived wind speed to wind speed measured by GoMoos buoy, DRDC met buoy, and ship-borne (CFAV QUEST) instruments (reproduced from [14]).

The fairly good agreement (R^2 = 0.87) between RADARSAT wind speed estimates and instrumental measurements re-affirms previous results that RADARSAT can be used to provide a good wide-scale estimate of wind speeds.

The ambient noise measured with the acoustic sensors (Figure 17) was compared to ambient noise modeled using a modified Merklinger-Stockhausen model [5]. A simple, ship-parameter model setting the peak noise level based on shipping at 60 Hz can be used for the shipping component of the ambient noise.
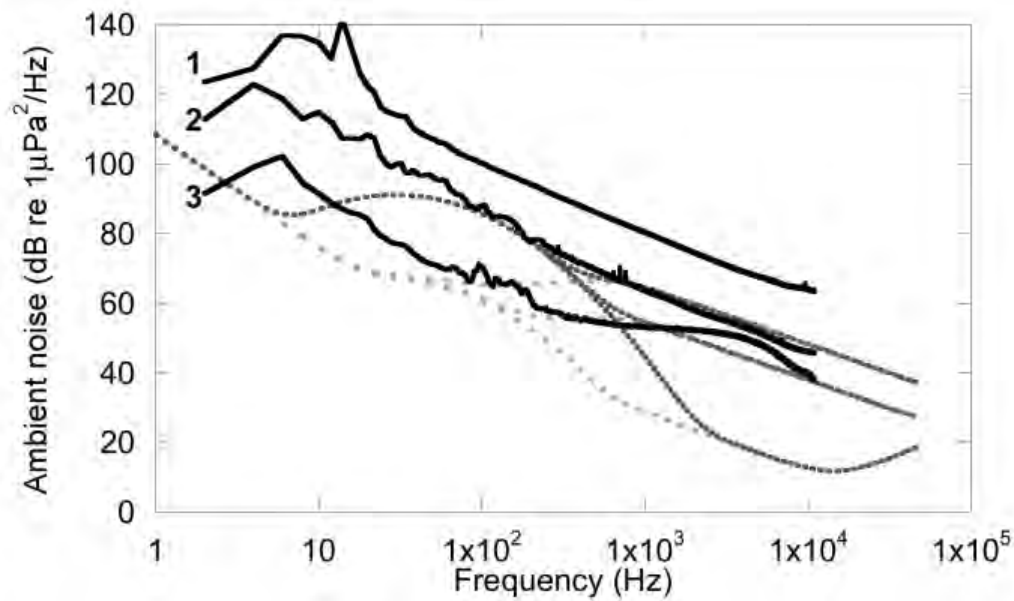
Figure 17 - Measured ambient noise (1) Sept. 16, 2008, 6.6 m/s wind speed; (2) Sept 17, 2008, 1.8 m/s wind speed; (3) Sept. 18, 2008, 0.1 m/s wind speed. Dashed lines show MS model results for given SAR-derived wind speeds, together with light and heavy shipping curves (light and heavy dashed lines) (reproduced from [15])

Figure 18 shows a comparison of ambient noise power spectral level measured during Q316 on one recording unit, during the periods when SAR imagery was collected (RADARSAT-1 on September 16th, R-2 on the 17th and 18th). There is an obvious dependence of the measured ambient noise on wind speed, demonstrating the potential for ambient noise estimates over a wide area to be derived from the SAR data. However, the measured ambient noise is considerably higher than that predicted by the Merklinger-Stockhausen model, particularly at the lowest wind speed (0.1 m/s). There is also wind speed dependence at all frequencies, including the frequency regime normally expected to depend on shipping noise.

Comparisons of measured ambient noise to modeled ambient noise power spectral level for Q325 are shown in Figure 18 and Figure 19. The model data shows the Merklinger-Stockhausen ambient noise predicted for the wind speed computed for the receiver location from the November 5th R-2 image, using the mean wind speed of 1.6 m/s and the mean wind speed plus and minus one standard deviation of 0.9 m/s. A moderate ship noise parameter of 70 dB was assumed for shipping noise.

Figure 18 - Measured vs. modeled ambient noise power spectral level for November 5th, 2009. The black line shows the mean ambient noise level, with the gray lines showing ± 1 standard deviation (reproduced from [14]). The model is based on a mean wind speed of 1.6 m/s and the mean wind speed plus and minus one standard deviation of 0.9 m/s.

There is reasonable agreement between the measured and modeled data above 30 Hz. The peak at 20 Hz in the measured data likely corresponds to fin and blue whale vocalizations that are not included in the model.

Figure 19 shows data for October 31st, 2009. In this case, the model data shows the ambient noise predicted for the wind speed computed for the receiver location. The noise prediction was made using the R-2 image from twelve hours prior to the ambient noise data collection. The wind speeds measured at the DRDC met buoy location at the time of the ambient noise acquisition were within one standard deviation of those measured during the R-2 image acquisition, and so the model results should therefore be valid. The mean wind speed was 8.7 m/s, with a standard deviation of 1.2 m/s. As the CFAV QUEST was on station near the acoustic receiver, a higher ship noise parameter of 76 dB was assumed for shipping noise. In addition to the whale vocalizations that are once again observed near 20 Hz, there are also low frequency tonals from the ship evident in the ambient noise spectrum.

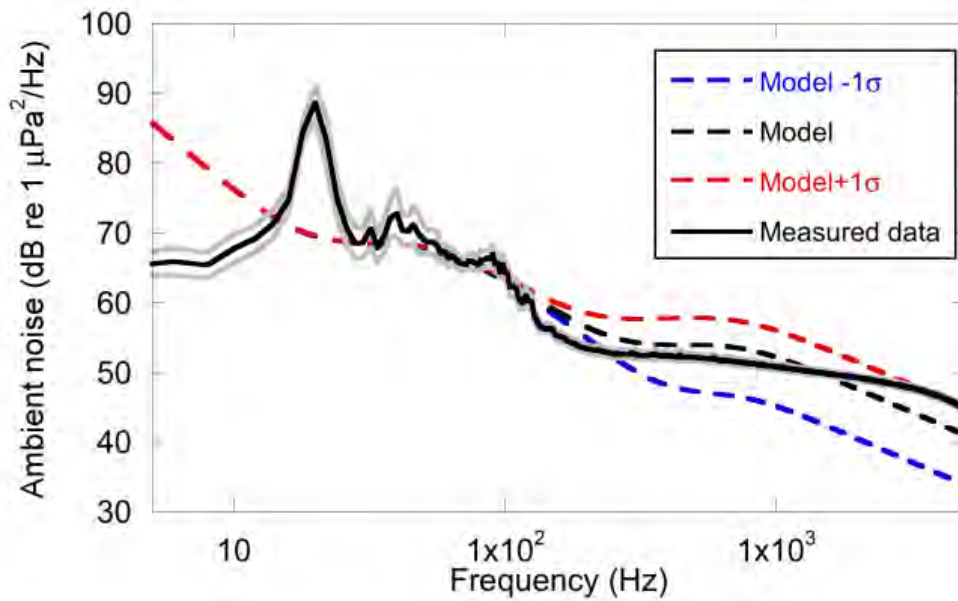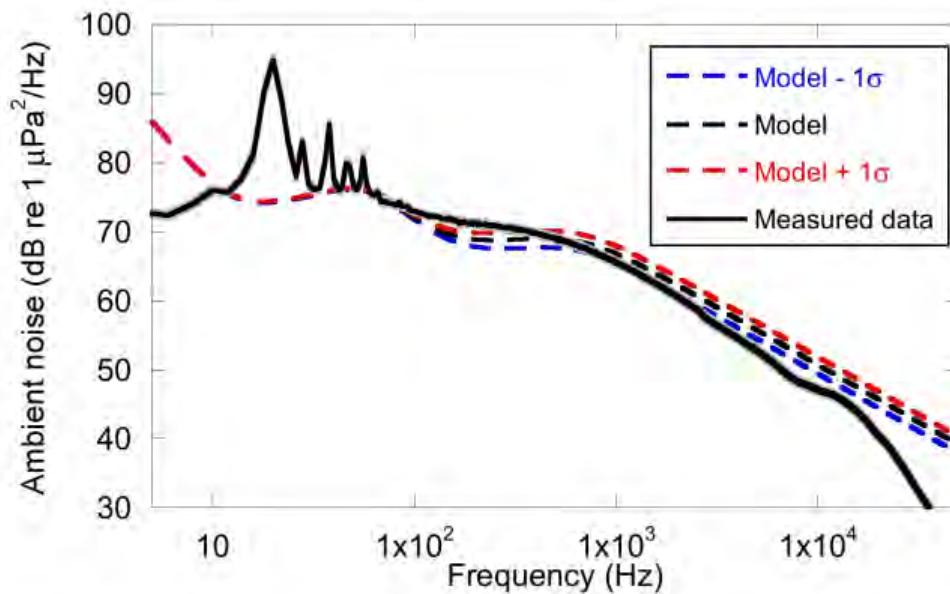*Figure 19 - Measured vs. modeled ambient noise power spectral level for October 31st, 2009. The black line shows the mean ambient noise level, with the gray lines showing ± 1 standard deviation (reproduced from [14]). The model is based on a mean wind speed of 8.7 m/s and the mean wind speed plus and minus one standard deviation of 1.2 m/s.*

In general, reasonable estimates of underwater ambient noise can be obtained using SAR imagery, although it seems that the accuracy of the ambient noise models may be location dependent.

WP 9.3 – Status: In progress.

Greater variability in ocean properties (*e.g.*, temperature, mixed layer depth, and sound speed profile) was observed during the first trial (Q316) than during the second trial (Q325). The increased variability was likely due to the location for Q316, which was at the edge of the Northeast Channel. At this location strong tidal currents and steep topography may combine to induce internal waves and turbulence, which will manifest as sound speed profiles that vary rapidly in both space and time. It was hypothesized that examination of sea-surface temperature (SST) images for each region for times and locations "near" the two TL experiment tracks might reveal differences in SST distributions, specifically, greater variance near the Q316 experiment area than the Q325 area. MetOc Halifax provided SST data with approximately 0.01 degree resolution to support this analysis; for these particular images, the measurements were all made by AVHRR.

In order to determine the impact of mesoscale ocean features on the ocean properties near the TL track, satellite SST observations were limited to those within 50 km range from the TL track and within 24 hours of the beginning and end of the TL experiments. Figure 20(a) is a sample SST image taken near the Q316 experiment area, while Figure 20(b) is the same image, masked to

show only pixels within 50 km of the ship track. A total of 12 SST images were available: 8 images for Q316, and 4 images for Q325. All the SST images were based on infrared radiometry; therefore, some pixels were obscured by clouds, especially near the Q325 experiment location, greatly reducing the available data. Table 1 is a summary of SST image details including the date and time of the image, the sensor, and the number of pixels that were used in the SST statistics.

Table 1 - Summary of images, sensors, and usable SST pixels.

Experiment	Image number	Date and Time (UTC)	Sensor	N_{pixels}
Q316	1	16-Sep-2008 03:01:05	TERRA-AM	12507
	2	16-Sep-2008 05:36:37	AQUA-PM	12507
	3	16-Sep-2008 07:14:27	AQUA-PM	12507
	4	16-Sep-2008 13:26:46	NOAA-17	10112
	5	16-Sep-2008 15:00:22	TERRA-AM	12290
	6	16-Sep-2008 15:06:13	NOAA-17	11996
	7	16-Sep-2008 18:20:17	AQUA-PM	12166
	8	17-Sep-2008 15:43:00	TERRA-AM	9543
Q325	9	04-Nov-2009 05:38:35	NOAA-18	1890
	10	04-Nov-2009 05:49:44	NOAA-19	1586
	11	04-Nov-2009 07:18:05	NOAA-18	6903
	12	04-Nov-2009 07:30:49	NOAA-19	7651
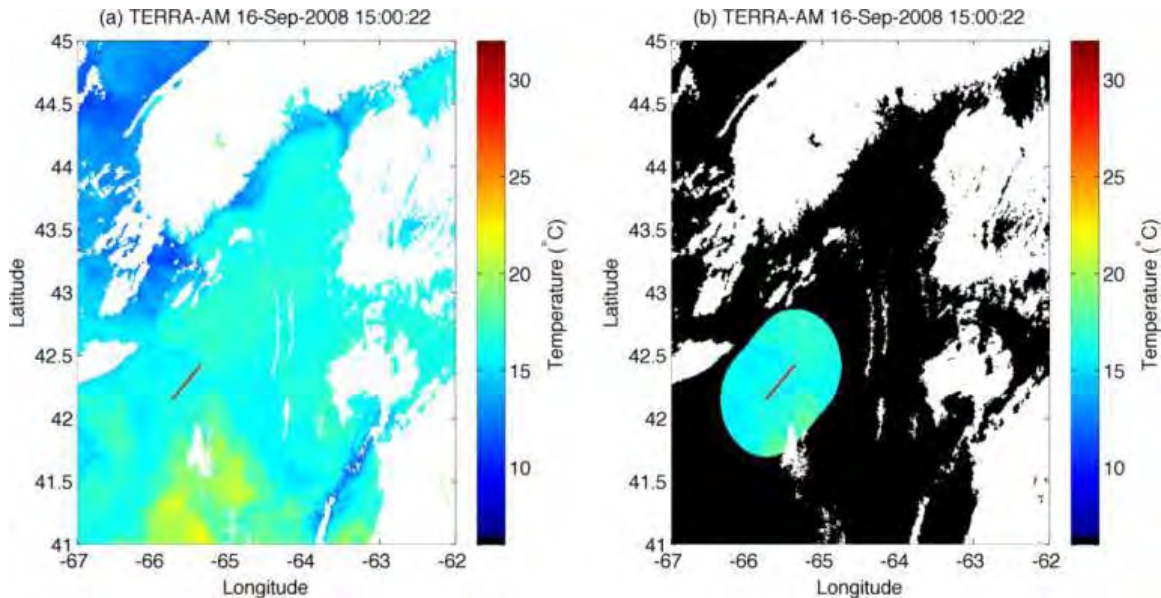
Figure 20 - (a) Sample SST image for Q316, with ship track indicated as a red line; white pixels are "bad" data points due to land or clouds (b) SST combined with image mask, creating a 50-km radius surrounding the ship track. All black and white pixels are excluded from further analysis.

For each image, a histogram was created of all the SST data points that fell within 50 km and 24 hours of the experiments (Figure 21). It appeared that the variance for the SST images from

Q316 was greater than that of the Q325 images. Therefore, the *F*-test [16] was used to determine the probability of the two datasets having different variances. The null hypothesis for the *F*-test is that dataset 1 has greater variance than dataset 2. Because the test is constructed such that the variance of dataset 2 is always the greater, a small value for the probability *P(F)* implies high confidence in rejecting the null hypothesis and concluding that dataset 1 has variance greater or equal to that of dataset 2, *i.e.* that the datasets are drawn from distributions with different variances.
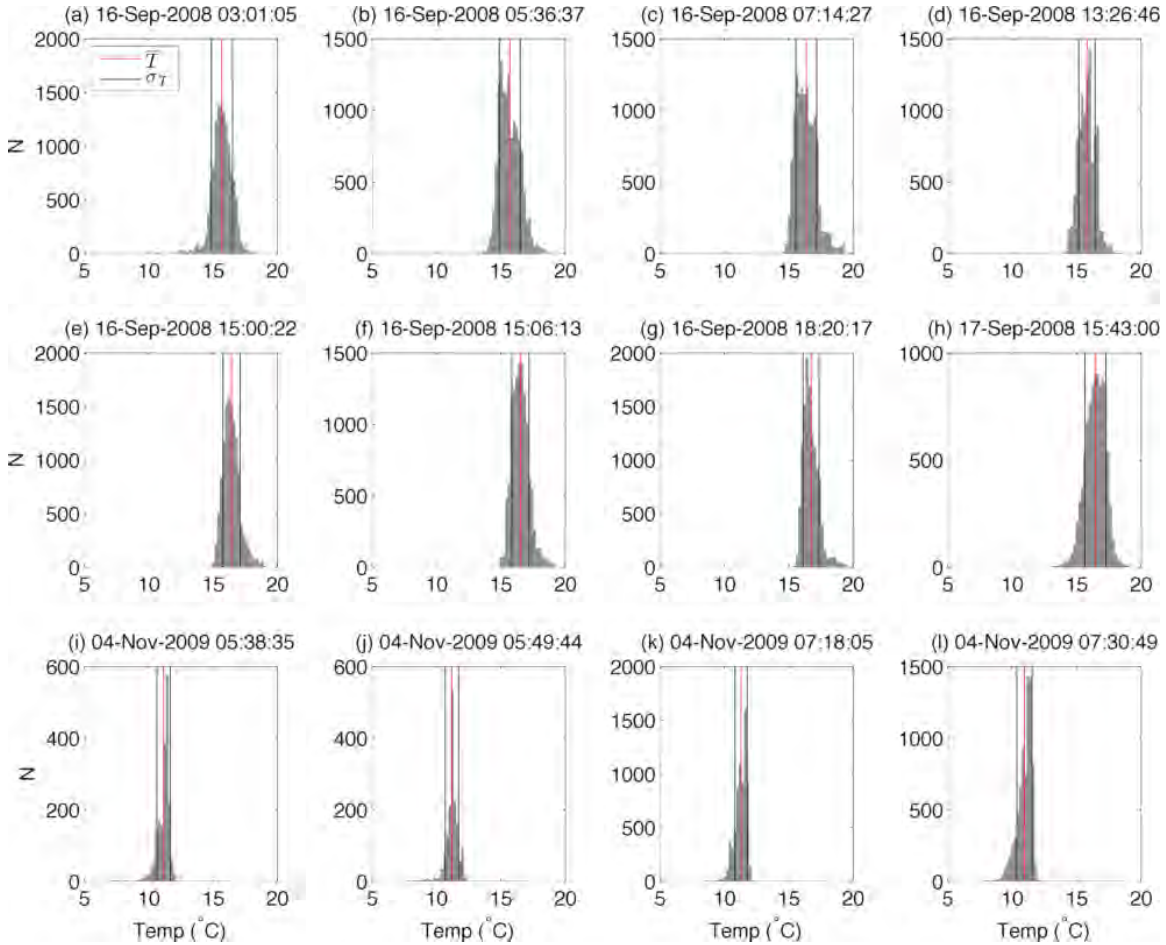
Figure 21 - Histograms of SST within 50 km and 24 hours of ship tracks for Q316 (a)-(h) and Q325 (i)-(l). Mean and standard deviation in SST for each histogram are indicated as red and black vertical lines, respectively.

The *F*-test was performed on all possible pairs of the 12 images, that is, pairs of images from the same experiment as well as one image from each experiment. A level of significance for *P(F)* of 0.05 was chosen. In the following table, pairs of images for which *P(F) > 0.05* are highlighted in pink (suggesting that the distributions have comparable variances), while pairs of images for which *P(F) ≤ 0.05* are highlighted in blue (suggesting that the distributions have different variances). Combinations below the main diagonal of the table (in black) are highlighted in grey because the lower half of the table is redundant.

If the SST variance was greater in the region near Q316 than Q325, one would expect to see two patterns in the table: the same-trial SSTs should have comparable variances (and thus be mostly pink), while the SSTs for different trials should have different standard deviations (and thus be mostly blue). In fact most of the pairs of SST distributions have significantly differing variances, whether from the same years or different years. Therefore, the results of the *F*-test are not particularly informative. This may also be due to non-normality of the underlying SST distributions.

Table 2 - Summary of F-test results. Pink indicates P(F) > 0.05, blue indicates P(F) ≤ 0.05, black and grey are used where the test does not apply. Image numbers refer to the images listed in Table 1.

	Image No.	Q316								Q325			
		1	2	3	4	5	6	7	8	9	10	11	12
Q316	1	black	blue	pink	blue	blue	blue	blue	pink	blue	blue	blue	blue
	2	grey	black	pink	blue	blue	blue	blue	pink	blue	blue	blue	blue
	3	grey	grey	black	blue	blue	blue	blue	pink	blue	blue	blue	blue
	4	grey	grey	grey	black	blue	blue	pink	blue	blue	blue	blue	blue
	5	grey	grey	grey	grey	black	pink	blue	blue	blue	blue	blue	blue
	6	grey	grey	grey	grey	grey	black	blue	blue	blue	blue	blue	blue
	7	grey	grey	grey	grey	grey	grey	black	blue	blue	blue	blue	blue
	8	grey	grey	grey	grey	grey	grey	grey	black	blue	blue	blue	blue
Q325	9	grey	grey	grey	grey	grey	grey	grey	grey	black	pink	blue	blue
	10	grey	grey	grey	grey	grey	grey	grey	grey	grey	black	blue	blue
	11	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	black	blue
	12	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	black

Two potential problems were identified in the datasets used in this analysis. First, the Q325 images were mostly obscured by cloud, especially along the SE part of the ship track; as a result, the images had about 1/5 as many usable pixels as the Q316 images. The coverage for Q316, on the other hand, was almost perfect. The smaller number of available data points for Q325 could have confounded the statistical results.

Second, the fact that the Q316 images were not obscured by cloud suggests that the weather was sunny. Solar heating can result in a difference of as much as 5ºC between the "skin SST" measured by satellite-borne instruments differing from the "bulk SST" measured by ships, depending on wind conditions [17]. Therefore, any increase in SST variance observed during Q316 might have been an artifact of diurnal heating. Figure 22 is a plot of temperature as a function of range from the track starting point, as measured by the ship's sensors and by the satellite-derived SST for images that overlap in time and space with the ship track on 16 Sep 2008 (sunrise was at 09:55 UTC). Uncertainty in satellite measurements of SST using AVHRR compared with in-situ measurements of the skin temperature is ± 0.3ºC [6] (bounds of uncertainty are indicated as dashed lines in Figure 22). The uncertainty in the temperature measured by the ship sensors is unknown. There may be weak evidence of diurnal heating since the satellite SST was lower than the ship temperature during the morning portion of the track (range < 22 km), but

higher during the afternoon portion of the track (range > 22 km). However, the temperature measurements in Figure 22 essentially agree within the uncertainty of the AVHRR measurements, suggesting that if diurnal heating was present that day it was a very weak effect.
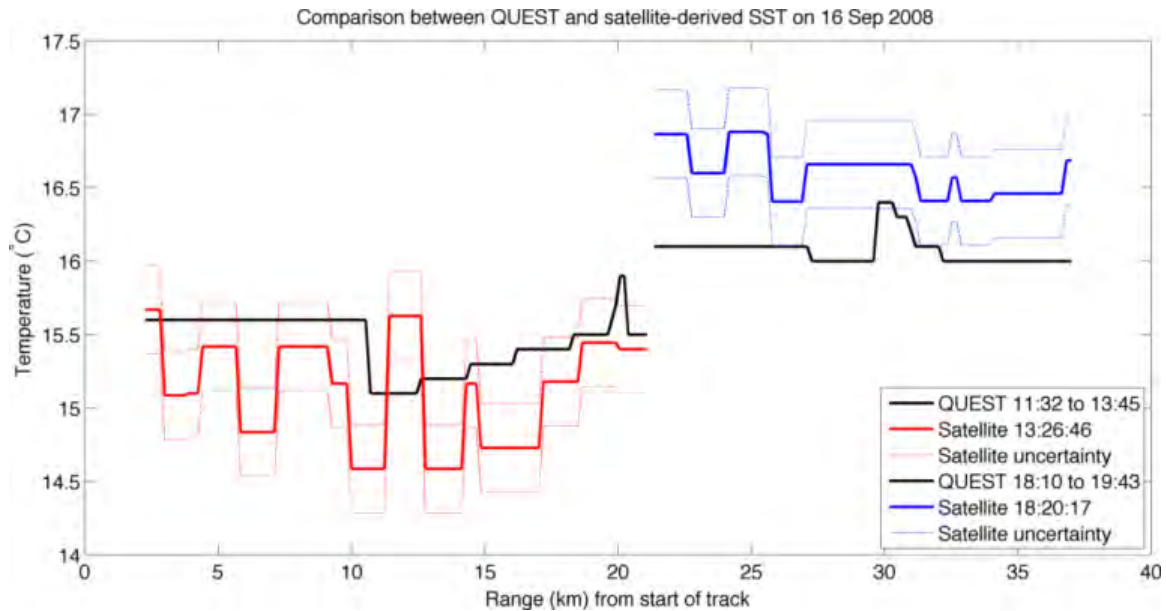
Figure 22 - Sea surface temperature as measured on board the ship (black line) and by satellite (red and blue lines, nearest-neighbour pixels) as a function of range from the start of the TL track for Q316 measurements on 16 Sep 2008. The track was traversed in two segments. Dotted lines indicate the approximate limits on accuracy of the satellite SST measurements. Accuracy of ship-measured temperature is unknown.

Although it appeared that the increased variance in ocean properties observed in situ during Q316 was also manifested in satellite SST images from the same time period, statistical tests did not support the hypotheses that the SST variances differed significantly between experiments and remained the same throughout a given experiment. Clouds obscuring the Q325 measurements may have confounded the analysis, and there may have been a small effect from diurnal heating present in the satellite-derived SST data. Overall, no firm conclusions can be drawn from these particular datasets.

2.9.3   Plan for FY 11/12

Another CFAV QUEST sea trial is planned for late June 2011 in a location near that where Q325 was undertaken. Although transmission loss experiments are not planned, ambient noise measurements will be undertaken, and it is expected that a set of oceanographic data will be collected for comparison to satellite imagery. Therefore, some further work will be undertaken on work elements 9.2, 9.3, and 9.4.

3   Summary

SOIN is a six-year research and operational development initiative that addresses barriers to implementing oceanographic applications of the Earth-observation sensors RADARSAT, AVHRR, MERIS and MODIS. Lead by MetOc Halifax, SOIN was launched in June 2007 with funding provided by CSA through GRIP. The project was divided into two phases with the first three-year phase focusing on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT. This report provides a summary of project activities and accomplishments during the ongoing Phase II of the project, in particular for FY 10/11.

Three new WP's commenced in FY 10/11, and with these came three new partners – IOS, RMC, and DRDC Atlantic.

DRDC Ottawa's SAR processor, IA Pro, CSIAPS and Canny edge detector continued to evolve and provide new functionality and advances in existing functionality that furthered the ability of SOIN to identify ocean thermal features. MetOc Halifax's OWS was further developed to ingest C-APS outputs and display these as part of its SST and OFA outputs, a key operational requirement. The installation of SOIN infrastructure at MetOc Esquimalt has expanded the project to a national level, and coincides with other west coast partners contributing to the effort. The introduction of IOS and ASL Environmental technology and continued R&D brought a much-needed ability to identify Pacific Ocean features using biophysical analysis tools and chlorophyll signatures. The involvement of RMC and their undertaking to develop a SAR ocean imaging model brings a new and exciting possibility to the ocean feature analysis arsenal. And finally, DRDC Atlantic's WP to determine the extent to which SAR-derived thermal features and winds can be used to characterize the acoustic conditions for naval sonar operations brings a new operational application for SOIN-derived technology.

SOIN members participated in many CSA led groups and committees such as EMOC and SARAWG, and attended various workshops and conferences, as detailed in WP 1.5. SOIN participants have seized many opportunities to promote the success and results of the project so far.

In summary, SOIN Phase I was a R&D success and has paved the way for a resounding conclusion in the form of SOIN Phase II. The SOIN project remains on schedule and on budget, and it is expected that all Phase II milestones will be achieved. The next two years promises to be very exciting as all SOIN WPs are brought to a close, and the implementation and operationalization of SOIN occurs on both coasts. Already receiving much recognition and applause, SOIN Phase II is poised to deliver new ground-breaking and operationally focused products that will integrate into existing and planned defence and security operations. Once operational, SOIN will be sustained through Canadian Forces MetOc operations, which are a component of Canada's maritime security operations, and through relevant components of cooperating departments.

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Annex A   GRIP Proposal summary tables

Work Packages commenced in FY 10/11:

Id WP 6.0:

Title:	**IOS**
Purpose:	West Coast Ocean Features
Work tasks:	6.1 Work Package management; 6.2 Detect, examine, and interpret oceanic frontal features off the BC coast using thermal, colour and radar imagery; 6.3 Link observed frontal features off British Columbia to coastal dynamic physical and biological processes; 6.4 Provide for implementation in IA Pro enhanced tools and frontal products.
Expected results:	Algorithms and research to assist with identification of fronts, eddies and thermal water mass boundaries on the west coast.

Id WP 7.0:

Title:	**SAR Ocean Imaging Model**
Purpose:	To develop a Canadian SAR imaging model for ocean features. The interaction of the sea surface with electromagnetic radiation of the frequencies, polarizations and incidence angles appropriate to spaceborne SAR sensors, in particular to RADARSAT-2 is then modeled, resulting in a predicted SAR image for the specific sea surface conditions.

Work tasks:	7.1 – Work Package Management:
	• hire personnel (Postdoctoral Fellow, MSc students);
	• develop working procedures and plan;
	• report on model status at bi-annual SOIN review meetings;
	7.2 – Conduct survey of existing SAR models:
	• assess merits of each model in the context of the requirements of the Canadian user community and for RADARSAT-2 sensor;
	• present findings to SOIN Team along with recommendation on which model to acquire;
	7.3 – Acquire agreed-to SAR model;
	7.4 – Install, modify and validate forward model:
	• rebuild model to run on RMC computing facilities;
	• modify model to run using inputs from MetOc IA Pro system and its successors for imaging parameters appropriate for RADARSAT-2 beam geometries;
	• validate model with field data and RADASRAT-2 imagery
	7.5 – Develop and validate inverse model:
	• investigate inversion feasibility and methodology;
	• recommend to SOIN Team on inversion feasibility:
	    ○ if feasible, code inverse model to run on RMC computing facilities using IA Pro inputs;
	    ○ if the inverse model is implemented, validate with field data and RADARSAT-2 imagery;
	7.6 – Integrate model into IA Pro and it successors:
	• explore feasibility and methodology for integration of the model into IA Pro;
	• recommend to SOIN Team on integration feasibility and techniques.

Expected results:	The predicted SAR image will be validated against images collected simultaneously from the SAR sensors. Many validations will be required under significantly different circumstances to gain confidence in the model. Once the model is validated, it will be inserted as an imaging tool into the SOIN operational suite.

Id WP 9.0:

Title:	**DRDC Atlantic**
Purpose:	Examine the extent to which SAR-derived thermal features and winds can be used to characterize the acoustic conditions for naval sonar operations.
Work tasks:	9.1 Work Package management; 9.2 Collect in situ meteorological, oceanographic, and acoustic data in the SOIN study area on a non-interfering basis during other DRDC R&D activities involving CFAV QUEST; 9.3 Predict underwater acoustic ambient noise levels using SAR-derived wind fields; 9.4 Predict underwater acoustic transmission loss through thermal fronts detected in SAR imagery.
Expected results:	Oceanographic conditions and ambient noise are two significant factors that govern the performance of naval sonar systems. This WP will assess the impact of SAR derived winds and fronts on naval sonar systems.

Annex B   GRIP quad chart

Government Related Initiatives Program – Project Overview

Canadian Space Agency / Agence spatiale canadienne

Project Title: Spaceborne Ocean Intelligence Network (SOIN)
Status: Phase II, Year 1 of 3
Lead Depart.: Department of National Defence [MetOc Halifax]
Keywords: maritime security, meteorology, oceanography, search and rescue, RADARSAT, AVHRR, MODIS, MERIS

Concept:
- Meteorology & oceanography (METOC) operations are overwhelmed with environmental information of civilian origin that they cannot use because: (i) it is not provided in operationally-compatible time frames and formats; and (ii) there are insufficient means to automate the product generation process;
- SOIN will address these barriers to operational use by: (i) developing image analysis, image processing and auxiliary data integration tools that produce METOC products in required formats; and (ii) integrating these tools and resulting products into existing and planned operations of MetOc Halifax, the Canadian Ice Service and the Joint Rescue Coordination Centre Halifax.

Objectives:
- To advance Canada's ability to produce operational METOC products for maritime defence and civilian security-related operations;
- To research & develop operational means to monitor mesoscale coastal & oceanic fronts and eddies with spaceborne SAR;
- To provide MetOc Halifax with the operational tools & infrastructure required to achieve these goals and to distribute resulting products to other agencies.

Description and Technical Approach:
- MetOc Halifax has established two technical teams – one that focuses on products based on thermal IR and multispectral imagery, the other on SAR;
- In Phase II of the project, products produced by both teams will be integrated into the METOC ocean workstation.

Results To Date:
- Thermal IR / multispectral APS system installed at MetOc Halifax;
- APS compatible OWS at MetOc Halifax and MetOc Esquimalt;
- Statistical modelling progress;
- Coastal & ocean fronts / eddies from SAR R&D continuing

Budget:

GRIP:	$1,210,000	(29%)
Lead Dept.:	$2,663,304	(63%)
Partner(s):	$ 334,454	(8%)
Total	$4,207,758	

Schedule:

Phase I Start:	FY 2007/08
Phase I End:	FY 2009/10
Phase II Start:	FY 2010/11
Phase II End:	FY 2012/13

Partners:
- DND [DRDC Ottawa, DRDC Atlantic];
- EC [Canadian Ice Service];
- DFO [Maurice Lamontagne Institute, Bedford Institute of Oceanography, Institute of Ocean Sciences]
- US Navy [Naval Research Laboratory - NASA Stennis Space Flight Center];
- Academic [Dalhousie University, Royal Military College].

Outputs for 2011-2012:
- Provision of an east coast frontal climatology
- Ongoing improvements to IA Pro, including statistical modeling;
- Commencement of SAR ocean image modeling at RMC
- Coastal & ocean fronts / eddies from SAR R&D continued;
- Extensive collection and dissemination of RADARSAT-2 data among project partners.

Canada

April 2011

Annex C   GRIP schedule

As shown in Table 1, SOIN Phase II will be delivered as a series of WPs, with each WP having defined objectives, resources, deliverables and schedules. See the annual report for definitions of tasks and items identified in Table 1.

.WP	FY 10/11				FY 11/12				FY 12/13			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	�	�	�	�	�	�	�	�				
1.1												
1.2.1												
1.2.2												
1.2.3												
2.1		▓	▓	▓							▓	▓
2.2					▓	▓	▓	▓				
2.3							▓					
2.4							▓	▓	▓	▓		
2.5	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
3.1	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
3.2	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
3.3	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
3.4	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
4.1	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
4.2	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓		
4.3	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓		
4.4							▓	▓	▓	▓		
5.1	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
5.2	▓	▓	▓	▓	▓	▓						
5.3	▓	▓	▓	▓	▓	▓	▓					
5.4	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	
5.5					▓	▓	▓	▓	▓	▓	▓	
6.1	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
6.2		▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
6.3					▓	▓	▓	▓	▓	▓	▓	
6.4					▓	▓	▓	▓	▓	▓	▓	
7.1	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
7.2	▓	▓	▓	▓								
7.3			▓	▓								
7.4					▓	▓	▓	▓				
7.5						▓	▓	▓	▓	▓		
7.6							▓	▓				
8.1	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
8.2	▓	▓	▓	▓	▓	▓						
8.3			▓	▓	▓	▓	▓	▓		▓	▓	
8.4	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	
9.1					▓	▓	▓	▓	▓	▓	▓	▓
9.2	▓	▓	▓	▓	▓	▓	▓	▓		▓	▓	▓
9.3					▓	▓	▓	▓	▓	▓	▓	
9.4					▓	▓	▓	▓	▓	▓	▓	▓

List of symbols/abbreviations/acronyms/initialisms

2CMV	Two-Colour Multi-View
3CMV	Three-Colour Multi-View
AMSR-E	Advanced Microwave Scanning Radiometer - EOS
AOR	Area of Responsibility
APS	Automated Processing System (NRL Stennis software)
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer (sensor on NOAA's polar orbiting satellites)
BIO	Bedford Institute of Oceanography (DFO, Halifax, Nova Scotia)
C-APS	Canadian APS
CB	Composite Bragg
CCRS	Canada Centre for Remote Sensing (NRCan, Ottawa)
CF	Canadian Forces
CFAV	Canadian Forces Auxiliary Vessel
CHL	Chlorophyll
CIS	Canadian Ice Service (Environment Canada)
CMOD	C-band Model
CODAR	Coastal Ocean Dynamics Applications Radar (HF radar)
CSA	Canadian Space Agency (Industry Canada)
CSIAPS	Commercial Satellite Imagery Acquisition Planning System (DRDC Ottawa software)
DFO	Department of Fisheries and Oceans
DND	Department of National Defence
DRDC	Defence Research & Development Canada (agency of DND)
ECR	External Client Report
EMOC	Enhanced Marine Order Coordination
EO	Electro-Optical
ES	Environmental Sensing (a Polar Epsilon capability)
ESA	European Space Agency
FLH	Fluorescence Line Height
FY	Fiscal Year

GIS	Geographic Information System
GMF	Geophysical Model Function
GRIP	Government Related Initiatives Program (CSA)
GSNW	Gulf Stream North Wall
GSNWSR	Gulf Stream North Wall Search Region
HF	High Frequency
HTML	Hypertext Markup Language
HYCOM	Hybrid Coordinate Ocean Model
IA Pro	Image Analyst Pro (DRDC Ottawa software)
IML	Institut Maurice Lamontagne (DFO, Mont-Joli, Québec)
IOS	Institute of Ocean Sciences (DFO, Sidney, British Columbia)
IR	Infra-Red
JGR	Journal of Geophysical Research
JRCC	Joint Rescue Coordination Centre (DND and DFO) Halifax
LCMM	Life Cycle Materiel Manager
LPC	Latest Pixel Composite
MABL	Marine Atmospheric Boundary Layer
MARLANT	Maritime Forces Atlantic
MC	Mean Composite
MCC	Mesoscale Cellular Convection
MERIS	Medium Resolution Imaging Spectrometer (sensor on ESA's ENVISAT satellite)
MetOc	Meteorology and Oceanography
MODIS	Moderate Resolution Imaging Spectroradiometer (sensor on NASA's Terra and Aqua satellites)
MSOC	Maritime Security Operations Centre
NASA	National Aeronautics and Space Administration
NDBC	National Data Buoy Center
NEODF	National Earth Observation Data Framework
NOAA	National Oceanic and Atmospheric Administration (USA)
NPAFC	North Pacific Anadromous Fish Commission
NRCS	Normalized Radar Cross Section
NRL	Naval Research Laboratory (USA)

NRTSD	Near Real Time Ship Detection (a Polar Epsilon capability)
NWGS	North Wall of the Gulf Stream
OFA	Ocean Feature Analysis
OGD	Other Government Department
OWS	Ocean Workstation
PE	Polar Epsilon
QuikSCAT	Refers to the SeaWinds Scatterometer aboard NASA's Quick Scatterometer satellite mission
R-2	RADARSAT-2
R&D	Research and Development
RMC	Royal Military College of Canada
SAR	Synthetic Aperture Radar
SOFDT	SAR Ocean Feature Detection Tool (an IA Pro tool)
SOIN	Spaceborne Ocean Intelligence Network
SSH	Sea-Surface Height
SST	Sea-Surface Temperature
WP	Work Package
WRF	Weather Research and Forecasting (a model)

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The Spaceborne Ocean Intelligence Network (SOIN) is a six-year research and operational development project that addresses barriers to developing and implementing oceanographic applications derived from Earth-observation sensors such as RADARSAT-2 and MODIS, capabilities that will be provided by the Polar Epsilon Project, combined with existing AVHRR and MERIS sensor data. The project is divided into two phases. The recently terminated three-year Phase I focused on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and an ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT-2 synthetic aperture radar (SAR) imagery. The ongoing three-year Phase II will focus on operationalization and implementation of SOIN capabilities. The SOIN project began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. This report provides a summary of project activities and accomplishments in FY 10/11.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

SOIN; RADARSAT; synthetic aperture radar; SAR; SST; ocean features; METOC

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